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ETHICS OF THE PETROLEUM GEOLOGIST.[1]

FREDERICK G. CLAPP.

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INTRODUCTION.

Questions of professional ethics arise sooner or later in every profession, and must be met and decided by the individual geologist for himself; although, in his decisions, he may be guided to a considerable extent by the customs of his fellow geologists and engineers, and by the particular relations in which he is

[1] Read before the Geological Society of America at the Albany meeting, December 28, 1916.

placed with reference to his clients, associates, employers, employees and the public.

In the older professions, like the law, medicine and the ministry, a paper on ethics would hardly be needed, since the subject has been so thoroughly determined by ordinary custom as to leave little doubt as to what practices are ethical and desirable, and those which are the contrary. Even in the profession of the consulting engineer, of which that of the consulting geologist may be considered a branch, certain rules and customs are generally observed. A petroleum geologist, however, is so new to the world, that no definite rules have been prescribed; and, even if such had been formulated in the past, they probably could not be universally adhered to, on account of the complexity of conditions, the various branches of the profession and the unknown future. Now, however, we have reached a period in which our profession is commonly recognized by the business and scientific world; and sooner or later every petroleum geologist must decide to what rules he will adhere.

The writer, on account of being a pioneer in the profession, was under the necessity of formulating his own code; and, with this in mind, searched with little success through professional literature for statements of prominent geologists or mining engineers which might serve as an ethical guide. Now that petroleum geology has become recognized as a profession, and many of the mooted questions have been answered, he takes the opportunity of presenting the subject to his fellow geologists, trusting that discussion of a code may result in the adoption of some standard that may serve as a guide for us all.

LITERATURE PERTINENT TO THE SUBJECT.

So far as known, nothing has ever been written, nor any discussion held on the ethics of a geologist. The first noteworthy discussion of a consulting engineer's ethics appeared in a paper entitled "Professional Morality," delivered by Mr. R. P. Rothwell in 1871[2] at the Bethlehem meeting of the American Institute

[2] *Eng. and Mining Journal*, Vol. 12, 1871, pp. 130–131.

of Mining Engineers. In this paper, some of the more obvious infringements of ethical principles by engineers were mentioned and condemned. Another noteworthy discussion of engineering ethics was given by Mr. J. C. Bayles in 1886 in his presidential address before the American Institute of Mining Engineers.[3] In 1906, a paper entitled "Engineering Honor" was delivered as the presidential address of Mr. S. S. Wheeler, before the Twenty-third Annual Convention of the American Institute of Electrical Engineers.[4] "It is an axiom," as stated in the Report of the Committee on Code of Ethics of the American Society of Mechanical Engineers,[5] "that engineers in all their professional relations should be governed by principles of honor, honesty, strict fidelity to trusts imposed upon them, and courteous behavior toward all."

Our province here is to go beyond this axiom, and discuss some of the ethical questions not covered by it. Mr. J. C. Bayles stated in 1886[6] that

> "Professional ethics are no different from the ethics of the Decalogue; they are specific applications of the rules of conduct which have governed enlightened and honorable men in all ages and in all walks of life."

Men of affairs, however, do not always stop to weigh motives, as any engineer or geologist ought to do, and the recklessness on the part of some men in our profession may well need curbing.

A much-quoted and much-discussed paper on "Professional Ethics" was delivered in 1908 by Mr. John Hays Hammond[7] at the Chattanooga meeting of the American Institute of Mining Engineers. Definite codes of ethics have been proposed or adopted by the Oregon Society of Engineers,[8] the Maine Society of Engineers,[9] the American Institute of Chemical Engineers,[10]

[3] *Trans. Am. Inst. Min. Engrs.*, Vol. 14, 1886, pp. 609–617.
[4] *Trans. Am. Inst. Elec. Engrs.*, Vol. 25, 1906, pp. 241–268.
[5] *Trans. Am. Soc. Mech. Engrs.*, Vol. 36, 1914, pp. 23–27.
[6] *Trans. Am. Inst. Min. Engrs.*, Vol. 14, 1886, p. 617.
[7] *Trans. Am. Inst. Min. Engrs.*, Vol. 39, pp. 620–627 (1908).
[8] *Eng. News*, Vol. 69, 1913, p. 1231.
[9] *Eng. News*, Vol. 70, 1913, pp. 1231–2.
[10] *Eng. News*, Vol. 69, 1913, p. 159.

the American Institute of Consulting Engineers,[11] the Pacific Association of Consulting Engineers,[12] the Pacific Northwest Society of Engineers[13] and the Western Society of Engineers.[14]

RELATION BETWEEN PROFESSIONAL ETHICS AND EXPEDIENCY.

We must clearly recognize at the outset that a great gulf exists between ethics and expediency. A procedure may be sound in a business sense as ordinarily understood, good policy for the individual or his client, and yet may break the Golden Rule and be ethically wrong. The writer of this paper believes that no such procedures should be countenanced by a member of our profession. On the other hand, a procedure may be honorable, fair and square in every sense, and yet may be poor policy (from the standpoint of an unscrupulous person). A good rule for the engineer and geologist, as well as for the business man, is to "*settle no question by expediency.*" There is, however, a class of expediency which we may illustrate by the following occurrence:

The writer, during his examinations of property, has frequently examined and reported on tracts on which he was later requested to report for other clients. While it would be a lapse of loyalty to client No. 1 to give the original data to client No. 2, there might seem to be no ethical objection to returning at a later date, surveying the tract a second time, ignoring the original data, paying no attention to its results, and making a second independent report on the same property. As a matter of fact, however, such a procedure would excite a suspicion on the part of client No. 1 that facts learned during his investigation might be divulged to client No. 2; and it would be unwise for the geologist to make the second report without definite permission from client No. 1. Here ethics and expediency coincide in their course of action. We must, however, in making any decision, make

[11] *Eng. News*, Vol. 65, 1911, p. 795.
[12] *Eng. News*, Vol. 67, 1912, p. 489.
[13] *Eng. Record*, Vol. 68, 1913, pp. 50–51.
[14] *Eng. News*, Vol. 75, 1916, p. 453.

sure in our consciences that apparent expediencies of the moment are not dwarfing our principles of professional ethics.

THE CONSULTING ENGINEER'S CODE OF ETHICS.

The gratifying statement was made by Mr. J. A. L. Waddell on page 485 of a paper before the Engineers' Society of Western Pennsylvania[15] that

> "It is essential for engineers to learn their system of ethics at the technical school, so that as soon as they start out in professional life, they will be able to put it into practice and thus avoid making grave mistakes which might mar seriously their future careers. Without a sound ethical system thoroughly established and practiced, the engineering profession cannot possibly attain its acme of influence in society; because it is only by concerted effort that such attainment is possible, and concerted effort is impracticable without a system of ethics, universally recognized and followed."

And again on page 489:

> "The young engineer should adhere as closely as he can to the ethics of the profession; and especially he should avoid subjecting himself to the slightest suspicion of dishonesty or even sharp practice of any kind. An engineer's reputation is as delicate as a woman's; and, if it be once really besmirched, it will be found next to impossible to rehabilitate it. The good things that a man does are often very quickly forgotten, but the bad ones are long remembered."

Unfortunately, we can go far through the curriculum of schools, colleges and universities without finding a consulting engineer's system of ethics properly taught. Courses of study, so far as known to the writer of this article, are entirely free from such teachings, and the question arises whether the eminent professors heading these courses have ever had occasion to answer the various practical questions for themselves. Many of them have not actually engaged in professional practice, except in vacations during the school year, and are unfamiliar with the delicate matters of ethics which arise daily in the life of an active consulting engineer or geologist. Even if such a system could be

[15] Vol. 32, No. 6, 1916, pp. 467–564.

taught, the young graduate would generally find himself confronted by phases of engineering actually very different from those postulated by his teacher, and needing different solutions. Hence, we return to the original supposition that every individual must make the final decisions of his own code to fit the peculiar conditions of his practice.

Some of the statements made in the discussion of Mr. Waddel's paper, above referred to, apply equally well to geologists as to engineers, and deserve a place here. As stated by Prof. William H. Burr (p. 542):

"The true cure for the professional deficiencies which lie at the foundation of the complaints or disturbed expressions which have been uttered, not only by the author of the paper under discussion, but by many others, involves a treatment of some characteristics of professional procedure among engineers and the consideration of some personal features of the matter which certainly would be unwelcome to many members of the profession.

"It is unfortunately an individual matter, not to say personal. Lack of breadth of educational training is undoubtedly responsible for many professional evils, not to say evils of individuality or personality.

"At the present time the engineering profession possesses practically nothing to indicate that it is a profession except the educational training given to its beginners in the engineering school; and that, as Dr. Waddell states, is in some respects seriously defective; but both the legal and the medical professions had their standing recognized and awarded by the community as a whole when the educational training of the members was even more narrow than the general educational work done in or prior to the engineering schools at the present time. Any land-surveyor, locomotive driver, or chauffeur even, may call himself an engineer, and the public as a whole will award him what he claims, while true members of the profession either do nothing or mildly criticize the procedure. . . ."

And, on the next page (543):

"Again, it might as well be frankly stated in such a discussion as the present that every experienced engineer knows there are many cases of procedure of members of the profession of such character as to fall far below the requirements of any worthy code of ethics, even if such existed. . . ."

This, also, is true to a marked degree among professional petroleum geologists. Continuing, on pages 543–4:

"A true and proper code of ethics is badly needed. It should be formulated and made known to the public at large in which engineers are to practice their profession. Such a measure properly perfected and set forth would go far toward securing proper recognition of the profession and the rates of compensation to which its members are entitled. In the absence of such a code, however, there will be irregularities, underbidding, jealousies, all too often with attendant evils of smallness and meanness utterly inconsistent and abhorrent to true professional spirit.

"The defects against which engineers contend are not those which can be cured by any improvement of education, nor by patting each other on the back and congratulating ourselves that we are members of the grandest of all professions and that there can be no human progress except that which as engineers, we create, all of which is little more than pure froth. When engineers, like other professional men, become finished practitioners, guided by high moral principles and earnest desire and determination to perform their duties in a thoroughly professional manner, it will not be necessary to resort to any adventitious means to secure public recognition or to agitate formal devices for the purpose of securing increased compensation. The best and most effective members of the profession secure satisfactory recognition and compensation at the present time; but unfortunately they constitute much too small a minority of professional workers. . . ."

A proper code of ethics for petroleum geologists will take time to formulate. We can, however, lay stress on a few principles which have been tacitly adopted by leading consulting engineers, recognized as standards for the profession, and which apply equally well to the geological profession.

CLASSIFICATION OF PETROLEUM GEOLOGISTS.

In preparing a code, it is obviously difficult to make one that will fit all classes of petroleum geologists, just as it would be to fit all classes of engineers. We must, therefore, as preliminary to the discussion, classify ourselves and our fellow petroleum geologists as follows:

A. Geological Survey geologists.
B. Employees of oil companies.

C. Those who are mainly investors.
D. Those who are mainly promoters.
E. Consulting petroleum geologists (including also geological and petroleum engineers engaged in similar professional work).

What may be right for a member of one of these groups, may evidently be the reverse on the part of some others. For instance, a geologist in the employ of the United States Geological Survey or of some State Survey may be within his privileges, when approached by the actual land-owner of the locality which is being studied, of mentioning the desirability of drilling for oil. The consulting geologist or the geologist employed by an oil company, however, might be doing his employers a great injustice by so much as hinting at such a possibility.

Even for a government geologist, the ethical lines are sharply drawn, and in the United States Geological Survey they are legalized by certain provisions of the Regulations (page 15), as follows:

> "The attention of all officers and employees of the Survey is called to that provision of the law which prohibits them from having personal or private interest in the lands or mineral wealth of the region under survey, and to that which prohibits the survey or examination of property for private parties or corporations. This legal prohibition applies to all members of the Survey holding appointments from the Secretary of the Interior, whether employed the whole or a part of their time on Survey work, and whether receiving an annual salary or a per diem compensation when actually employed. . . ."

This regulation, so far as known, has been implicitly followed. A government employee is naturally supposed not to divulge information to other than property owners; but, on the contrary, a consulting geologist may be free to give hints and advice broadcast, so far as these do not affect the interests of his clents or the particular tracts of land being reported on.

There should be no misunderstanding the distinctions made in this classification. Between *A* and the others, there can be none. Between *B* and the others, there generally is none, though the

distinction between *B* and *E* is not always publicly known; and can generally be estimated correctly by considering whether the geologists in question give all of their time to one particular company, or act instead in a consulting capacity. Only a few members of Class *C* exist, viz.: Geologists who hunt for and find oil propositions in which they may invest their own funds. The members of Class *D*, who search out favorable propositions, giving financiers the opportunity to invest in them, are more numerous, and of many ethical shades. Between Classes *D* and *E*, the gap may be great or small, according to whether the geologist maintains himself scrupulously as a professional man, or whether he is willing to accept "interests" in companies or properties, to sign his name to promotion reports, to solicit subscriptions for stock, or to use any other of the numerous methods which a geologist can use as an entering wedge into the oil business.

Hence, a petroleum geologist of Class *D* is the one who might be supposed to need watching by his associates and the public; and this is the class into which a "quack," "oil smeller," or "pseudo-geologist" may be expected to seek recognition. No place in the classification is allotted to "quacks," "oil smellers" and "pseudo-geologists," since the present paper is only concerned with honest questions asked and pondered by honorable members of the profession, who are here presumed to be in good standing and capable of serving efficiently in their respective careers. We are not considering the "scum" or "parasites" of the profession, who unfortunately abound; but Class *D* consists of geologists who have in some cases organized new development companies, placed promising properties on the market, etc. The distinction between Classes *D* and *E* is a matter for the individual, who may sometimes belong in both classes. This condition will be referred to later; and we need simply explain here that the present paper is concerned mainly with these two classes.

OUTLINE OF ETHICAL CODE FOR THE CONSULTING PETROLEUM GEOLOGIST.

Having classified the members of our profession, we will now take up the questions which the consulting petroleum geologist is likely to ask himself, endeavoring to give at least partial answers to his perplexities. Owing to the abnormal growth of the profession and to the numerous additions of young geologists to it within the past five years, the discussion of Classes *D* and *E* (promoters and consulting geologists) separately seems impracticable. Unfortunately few members of the profession exist who are entirely free from promotion activities. While our brother geologists, who have transferred their activities to Class *D*, are in most cases honorable gentlemen, who have found something valuable; and, while entitled to a good profit on it themselves, are assisting in the development of the country by placing the proposition in the hands of financiers able to handle it, a real public misfortune nevertheless exists in the fact that more of the consulting geologists have not held strictly to the consulting side of the profession,—*i. e.*, that of examining and reporting on properties for a definite fee or on a salary basis, to the exclusion of "contingent fees" or "interests" in the profits, by which they are tied up or become recognized as affiliated with some particular promotion or development company. The rapid growth of the oil business and the great profits derived from it in some cases have caused this condition of affairs, on account of which the strict consulting profession has few adherents among the multitude of real and assumed petroleum geologists; the remainder ranging all the way from partial to full-fledged promoters.

Our ethical system for Classes *D* and *E* jointly may be outlined somewhat as follows:

I. Relation between geologist and client.
II. Relation between geologist and assistants.
III. Duty of the professional man to the community.
IV. Relation of the geologist to other members of the profession.
V. The question of fees.

VI. The question of promotions.
VII. The matter of offices.
VIII. The matter of reports.

I. RELATION BETWEEN GEOLOGIST AND CLIENT.

Mr. R. P. Rothwell remarked as long ago as 1871[16] that

"I consider the engineer who receives, or allows to be received by any one else, commissions on the material employed in his works, is not acting honestly or honorably, and should be deemed unworthy the honor and dignity of our profession."

This view was stated again by J. C. Bayles in 1885,[17] by John Hays Hammond in 1908[18] and by various codes of the engineering societies. A similar statement might now be made in regard to commissions on oil properties recommended by a petroleum engineer or geologist.

The matter of duty to one's client or employer is mentioned by the Committee on Ethics of The American Society of Mechanical Engineers[19] as the first obligation of an engineer. The rule can perhaps be summarized for the petroleum geologist no better than is done by that Committee, viz.:

"An engineer cannot honorably accept compensation, financial or otherwise, from two or more parties having conflicting interests without the consent of all parties."

A similar article has been inserted in all codes adopted by engineering societies, so far as noted. Hence, it follows with us, as with them, that

"The engineer, in whatever capacity, whether consulting, designing, installing, or operating, must not accept commissions, directly or indirectly, from parties dealing with his client or employer."

This means, when applied to the petroleum geologist, that he

[16] *Eng. and Min. Jour.*, Vol. 12, 1871, p. 130.
[17] *Trans. Am. Inst. Min. Engrs.*, Vol. 14, 1886, p. 611.
[18] *Trans. Am. Inst. Min. Engrs.*, Vol. 39, 1908, p. 623.
[19] *Trans. Am. Soc. Mech. Engrs.*, Vol. 36, 1914, p. 23.

must not receive any compensation on account of machinery, material or property which he may recommend. If, after making a favorable report, resulting in the leasing of a certain tract of land by his client or employer, the property owner should approach him with an offer of compensation for so doing, the geologist would be bound by duty to decline it.

A matter of some importance in the relations of engineer and client was brought up by John Hays Hammond in 1908[20] in regard to "whether it is professionally proper to make a report for the seller of a mining property"; the decision being that nothing unprofessional exists in the practice, provided the engineer does not suppress or misstate facts, disguise or withhold his honest opinion. The danger was recognized that such a report might later be used as if it were advice offered the purchaser. Hence the fact of a report being made for the vendor or owner of a property should be frankly stated in the report. This sort of business is undesirable as a rule, and practical wisdom, rather than ethics, condemns it. Authorities almost universally agree that an engineer who does make a seller's report can not legitimately take payment in the shares of a company floated on the basis of that report, "as even the most honest of men is liable to be unconsciously biased under these conditions." Professor Henry Louis in a discussion of Mr. Hammond's paper[21] even recommended going so far as never to own a single share in any mine or mining company. This is a worthy ideal of the best professional ethics, but is adhered to by very few and is more a question of expediency than of ethics.

We must assume as an axiom the statement of the Committee of the Mechanical Engineers that

> "If an engineer uses information which is not common knowledge or public property, but which he obtains from a client or employer, resulting in plans, designs, or other records, these should be regarded as the property of his client or employer."

This rule applies equally well to the geologist; and in fact is

[20] *Trans. Am. Inst. Min. Engrs.*, Vol. 39 (1908), p. 621.
[21] *Trans. Am. Inst. Min. Engrs.*, Vol. 40 (1909), p. 853.

mentioned in the Regulations of the United States Geological Survey, where (page 17) we read as follows:

"Information of a confidential character, such as railroad and mine maps, drill records, etc., is frequently supplied to members of the Survey by private parties and corporations. Such information must be carefully guarded and used only under the conditions stipulated by the persons furnishing it. Whenever desired, a guarantee to this effect will be furnished over the Director's signature."

"The right to sell information to another where the first employer has hopelessly failed to pay his bill," brought up in a letter of Mr. Victor G. Hills to the *Mining and Scientific Press*,[22] appears to be of easy solution. The geologist or engineer may be presumed to have been put to heavy expense for travelling and field work, as well as to have used up valuable time in the work; and he is probably warranted in taking the fullest steps to secure some return.

Offenses in the improper use of reports are probably more often the fault of the client than of the geologist. We may take as an example a case where geological survey, drilling recommendations and development advice are demanded, and a report prepared, supposedly for the information of the client as to acquisition and development of the leases. Later it develops that the client is not a capitalist, as supposed, but is seeking funds, not only for drilling operations, but also for completing payment on his option, and the geological report is published by him in a stock-selling circular.

Such cases are fairly common in our profession, and the question arises as to consequent proper procedure. Probably there is no remedy when once printed report has been circulated; but we can refuse to report again for the same client without guarantee that our professional ethics will not be brought into jeopardy. The geologist can partially control the uses to which his report is put by inquiring its purpose in advance, and by refusing to do what his conscientious policy finds objectionable, as would be the permitted use of his report for promotion purposes, without

[22] *Min. and Sci. Press*, Vol. 107, 1913, p. 976.

being absolutely sure that no statement was misleading or any word picture overdrawn. In fact, his statements should be a plain record of facts, without unnecessary adjectives or rhetorical flourishes.

In most cases of professional work, the client is the employer and the geologist the employee, and the latter is working for a lump sum fee or per diem salary, presumably shifting frequently from one piece of work to another and from one employer to another. This is our privilege as professional men. We are at liberty to report today on a big tract for a large corporation, and tomorrow to make a competitive report for a small adjoining land-owner as to the value of his farm for development, and perhaps the next day shift back to the territory of the large company. The public recognizes the right of a professional man to do this, and if he be a geologist of unquestioned integrity, few will question his actions or motives in so doing. He must be careful, however, not to give either client—the wealthy corporation or the struggling farmer—any hint of the results discovered on the acreage surveyed for the other. This is one of the most important points to be borne in mind and universally adhered to. We might call this rule *The Inviolability of Professional Confidences;* and in our opinion, it does not permit of any modification.

To illustrate by an experience: A geologist was asked to examine a large territory in a foreign country for clients in still another country. The project was abandoned. Some years later a prospective client expressed his desire to see a sample report, for the purpose of judging what kind of report he might expect to receive in return for his contemplated expenditure. The matter was taken under consideration, the report mentioned was selected by the geologist as the best illustration, and the engineer representing the original clients was then asked for permission to show the report for the purpose desired. The reply was as follows:

"We should very much like to oblige you, but we are strict in our interpretation of our obligations to our clients. In no case do we feel we have a right to show our reports to any people other than our clients, without the direct permission of our clients."

Such examples prove that only the straight and narrow path is open for the consulting engineer or geologist if he would achieve success and win the approval of all clients. His duty to them does not cease when the report is given, but like a lawyer, he must be ever diligent in maintaining not only the letter but the spirit of his clients' confidences. Please note that the word "confidences" is used in a broad sense; not only to include what has been confided to us by a client, but what has been learned on any subject which it is to the client's interest to keep secret. We have seen that it is essential to hold unreservedly to the interests of a client, both in fact and in appearance. This rule must be adhered to in the face of competition and monopoly throughout our professional work and subsequent career.

Some geologists, having been engaged on an areal survey, completed the work and entered the employ of other clients, have later been called again to report on the original locality, after the first client had absolutely abandoned it. During a discussion of the ethics of the question, the answer has been made that "Oh, the company has abandoned the lease; there is nothing to prevent the report being now made for the prospective client who is considering it." While such an attitude might be correct after soliciting and obtaining the approval of client No. 1, it is a dangerous attitude to take without his approval, and one sure to bring disaster if persisted in. Even if the original client has abandoned a lease for years, he may return at some future time and develop it.

Another illustration is taken of a large tract which was examined and reported on in detail. No special mention of the exclusive character of the report was made; but, since this is the policy commonly maintained in the absence of other arrangements, no idea was held that the report or data would ever be used for other parties. Some years later another client wished a report on the same area, and it became necessary to ask the authority of client No. 1 to use the data for client No. 2. The matter was one in which there could be no competition, yet the desired permission was refused. Since, however, it was very

essential for client No. 2 to have this data, and since there would be no competition, it was manifestly the geologist's duty to negotiate for an exchange of data, which was arranged to the satisfaction of both clients.

II. RELATION BETWEEN GEOLOGIST AND ASSISTANTS.

In discussing our ethical code, it behooves us not only to consider our own duties and actions, but also what we must expect from other persons in our profession. Some of us are employers, while others are employees. We must, therefore, adopt such ethical ideals as would be equally fair and right were our positions reversed. Since this discussion is limited mainly to two classes of petroleum geologists (*D* and *E*)—those acting simply in a professional capacity and those whose business it is to discover new propositions and to capitalize them—we are not discussing the relations between employer and employee in any corporation or governmental survey, but simply those relations established in our professional work on a professional basis. A similar rule applies between the geologist, when the latter is an employer, and assistant geologists in his employ, as applies between client and geologist. The assistants are in duty bound to observe the rule of Inviolability of Professional Confidences; both on account of the client and of the more immediate employer—the geologist.

Furthermore, an assistant geologist has no moral right, while still employed, to negotiate with a client of his employer for the purpose of leaving such employ and securing the client's business for himself. The same high standards of professional ethics should prevail among consulting geologists, whether employers or assistants, as prevail between similar classes of lawyers, doctors, or other professional men, where it is a serious breach of professional ethics for one member of the profession to steal or attempt to steal his employer's business. Unfortunately, these matters of ethics have not been uniformly observed by members of our own profession. A client of one professional man should be held by the profession to be so, until the client himself shall choose to make a change.

III. DUTY OF THE PROFESSIONAL MAN TO THE COMMUNITY.

The question now arises: What is and should be our relations with the public? *Is our profession under any obligations to the community or country? We believe this question must be answered affirmatively.*

The word "profession" is defined by Webster's New International Dictionary as:

> "A calling in which one professes to have acquired some special knowledge used by way, either of instructing, guiding or advising others, or of serving them in some act."

Hence, a consulting geologist is, properly speaking, a professional man, as is also a teacher of geology, or an employee of one of our national or state surveys. A geologist engaged in promotions would not be, strictly speaking, a professional man, though for the purposes of our discussion we will include him.

In considering the original three learned professions: law, theology and medicine, we find that all members of a profession are advisers, as is also a consulting geologist. These professional men are receivers of confidences, and are trusted not to betray the latter. They are given great responsibilities, on which life or death frequently depend. The position of the consulting geologist may not be so critical; nevertheless he must frequently render an opinion on which hinges the expenditure of millions of dollars. He must, above all, retain confidences, since he is believed by the public to be an impartial authority of last resort on certain matters. Acting in such capacities, he is a professional man, but he ceases to be strictly so if he deviates far from this advisory career into the mazes of promotion, finance and development. Just where the limit is, none of us can say, except perhaps in our individaul instances. The promoter, business man and financier are needed by the world just as is the consulting specialist; but only the latter can be consistently classified as one of the profession.

What then are the duties of professional men, in order to retain their standing in the community or profession? They must,

in the first place, serve their clients to the best of their ability. They must even refer to other members of the profession any matters on which they are not qualified to advise or report.

Sir Francis Bacon wrote, in the preface to his "Maxims of the Law," as follows:

> "I hold every man a debtor to his profession; from the which as men of course do seek to receive countenance and profit, so ought they of duty to endeavor themselves by way of amends to be a help and ornament thereunto."

An extract from the code of ethics of the Oregon Society of Engineers[23] puts this maxim in a nutshell, viz.:

> "Engineers should be willing to assume their proper share of public work, and to render all assistance possible for the general good of the community."

In short, engineers (with whom we include petroleum geologists) are expected to forget the temptation of the "almighty dollar" in their service to the community; and, if, perchance, in spite of their professions, they are induced to swerve into the paths of business or finance, they are expected to do so openly. We, as consulting geologists, have frequent opportunities for profit by interrupting our consulting careers to engage in some particular venture. Some pioneers in the profession held out for years against any deviation from the strict professional standpoint, only finally becoming interested in certain properties after discovering that services to the community and to the oil business could be rendered more efficiently from this standpoint.

There is undoubtedly a moral gain in remaining a professional man; but the disadvantage exists that much is expected of him with comparatively poor financial return. We have the privilege, as consulting specialists, of charging fees commensurate with the value of the advice to our clients, which is great in some cases; so that if we are efficient specialists, our clients should and do expect to pay high fees. In return for the privilege of charging, however, we must be prepared to serve the community when

[23] *Engr. News*, Vol. 69, 1913, p. 1231.

necessary, and even of giving up professional engagements for this purpose. *To a professional man, the good of the community should rank first and that of the individual afterwards.*

Since we have said that loyalty to a client is of first consideration, some may ask, "*Suppose the interests of the community clash with those of a client?*" In maintaining this loyalty, therefore, we as professional men also reserve the privilege of accepting or declining any piece of work. We are free to decline if, in our judgment, it is not for the best interests of the community, state or nation. We can advise an industrial concern to use certain gas fields or fuel in its plant; but, if we believe that natural gas ought to be used strictly for domestic purposes, we can decline a piece of work in which we would be obliged to advise taking domestic gas away from a needy community in favor of factories, cement plants or smelters. Probably this is an ideal rarely reached by the geologist or engineer, nevertheless *here we may owe a greater duty to the community than to any prospective client;* and the same would be true in case of war or other public calamity, when the geologist would be called to devote his knowledge to the service of the nation.

Another way in which we can serve the whole public is in helping to clean out, so far as possible, "quacks," "pseudo-geologists," and "oil smellers," who are hangers on and do their best to ruin the legitimate consulting profession. Multifold quotations from would-be geologists appear in the press, describing geological and petroliferous conditions that can not exist in nature, and these should be dispelled, so far as possible, by the enlightened geologist. It is our duty, as professional men, to warn our clients and the public against false so-called "experts" for instance, like those who have "traced rivers of oil" from Canada through the Appalachian fields to Louisiana, under the Gulf and into Mexico, as was claimed by one of them; or, like another who was able to place his divining rod instrument in a certain attitude over a small sample of earth brought from the surface of some distant region, whereupon the instrument was supposed to record "oil," "gas" or "dry." It is strange that, within a

few years, some men prominent in the oil business have believed in such delusions, and while oil operators are now more cautious, they seem to have swung to the extreme of crediting as infallible any one calling himself a "geologist," disregarding the scientific knowledge or experience of the latter. Since there is no standard practice by which a client or a capitalist can distinguish between the true and the false, it behooves us, as a profession and as credited experts, to clarify the situation as much as possible.

IV. RELATION OF THE GEOLOGIST TO OTHER MEMBERS OF THE PROFESSION.

Is a consulting specialist under any obligations to other members of the profession? We believe that he is; and that, while these obligations are less definite than those to clients, employers, employees or to the public, they are nevertheless tangible.

First, the geologist or engineer must maintain the high standard, morally, technically and economically, that his fellow members adhere to. His honesty and integrity must be unquestionable. He must use the greatest care to prepare reports which will not only give the very best advice; but he must state carefully which they purport to be—reconnaissances or reports complete in detail—and he must not lend his name to any questionable enterprise. If scientific articles or books are published, full credit must be given to all persons who are quoted or from whom ideas are obtained.

Secondly, the consulting geologist or engineer must not denounce or seek to expel any professional brother from a position or clientele, or take any unfair advantage. In the words of the Committee on Ethics for the American Society of Mechanical Engineers[24]

> "Before any consulting engineer takes over the work of another consulting engineer, he should ask the client his reasons for desiring to change engineers; and, unless the consulting engineer is entirely satisfied that the client has good and sufficient reasons for making the change, he should confer with the present incumbent before accepting the work."

[24] *Trans. Am. Soc. Mech. Engrs.,* Vol. 36, 1914, p. 124.

And, furthermore,

"Consulting engineers should not say or do anything to impair confidence in the engineer in charge, unless it is apparent that he is wholly incompetent, or the interests of the profession so require."

The same rule should apply to consulting geologists.

In the codes adopted by various engineering societies, members are expressly prohibited from attempting to supplant a fellow engineer in the employ of any client. Underbidding is condemned in many codes. It is also prohibited, in the words of the Pacific Association of Consulting Engineers,[25]

"To attempt to injure, falsely or maliciously, directly or indirectly, the professional reputation, prospects or business of a fellow-engineer."

Probably every geologist and engineer has had reports of other persons submitted to him, and asked for his opinion of them. We assume that he will always give his unbiased judgment, whether or not he is to be paid for the advice. Most of this will be verbal and informal, and he is serving the community by giving it. Sooner or later, however, he will be shown reports made by members of his own or allied professions, and will be asked for a written report on the same property based upon them. This, in our opinion, the professional man will refuse to give, unless absolutely certain that the reports and data given are authentic, just as a justice of the court would refuse to accept a questionable written report as testimony to base a decision on it, without the positive evidence of witnesses. No member of the profession should formally render a report based on miscellaneous data submitted to him unless the nature of the evidence is directly mentioned. At all times, he must have positive evidence, either from his own observations or those of trusted men, that conditions are as he states them to be. *By such procedure, he protects members of his profession as well as his clients.*

V. THE QUESTION OF FEES.

In connection with fees, no ethical question seems to be involved. The supposition is that three factors control a profes-

[25] *Eng. News*, Vol. 67, 1912, p. 489.

sional fee, viz.: (*a*) The experience and ability of the expert; (*b*) the value of his time for other purposes, and (*c*) the value of the particular work to his client. There is no injustice to a client in charging what the business is worth; but there is a certain injustice to his fellow geologists in putting his fee below the recognized fees of the profession for the grade and experience of work rendered.

In the majority of cases, the prospective client asks in advance to have a definite fee mentioned. The geologist wavers between the minimum price at which he figures he can do the work and the maximum which he believes he ought to obtain. He is similarly situated as is a contractor, who, if he receive the business at his minimum bid, will get little remuneration for his efforts; if, on the contrary, the maximum figure be named, he may lose the contract. In such doubtful cases, the decision of the geologist may be to ask himself how much his time is worth for other purposes. That is, if he can engage in more remunerative business, he ought, in justice to himself, to ask the maximum, thereby losing the particular piece of work. If, however, he has plenty of time, he may offer to do the work at the minimum rate.

Some thought has been given to this phase of the subject, because a successful engineer is frequently criticized for placing his fees too high. Our reply is that no maximum figure can exist; there is no ethical consideration prohibiting a member of the profession from asking what he believes the business is worth, leaving his clients free to accept or decline as they see fit.

In the case where no estimate has been asked in advance, the question is more complicated; since it is manifestly unfair to lead a client into having a report made, then to charge a fee greater than the customary one. In such a case the question should be mentally asked: "How much is this report worth to my client?" The answer will generally guide the geologist or engineer in fixing his fee.

In earlier days of his profession, the writer was somewhat embarrassed when demanding a fee, and in most cases probably underestimated the value of his work to his clients. As he pro-

gressed, however, the demands on his time became so numerous as to require a change; this being achieved in part by the employment of assistants, and further by raising his fee. Up to that time, a uniform per diem fee had been charged; but in raising it arbitrarily, he made a serious mistake. Some of his clients received the change philosophically, but several cases come to mind where the jump gave an unfavorable impression, and no further business was received from those sources. True, the effect was as intended, viz.: an increase of time for other work; but this had not been desired as the cost of the good will of a single client. The mistake was not made a second time, and a few reports are still made for certain of his original clients at the original minimum figure. The theory is that any fee, no matter how high, is permissible, if its amount be mentioned in advance; but that a raising of professional fees to an established client, while ethically right, is neither expedient nor strictly in accord with professional etiquette.

While it is probable that the fees received by a petroleum geologist compare favorably with those in most classes of consulting engineering work, it is a fact that all engineering fees of recognized experts for the best class of work are less in proportion than are those in similar grades of work by the medical and legal professions. Indeed, there seems to be an undercurrent of popular opinion that engineering advice is worth less than is legal advice. In an address in 1915 by Dr. George F. Swain before the American Institute of Electrical Engineers, he gave his opinion that the reason for this is that the engineer does not appeal to sentiment as do the lawyer and doctor. There is no evidence that the engineer or geologist is less competent or less educated than are other professional men; and the consensus of opinion of authorities high in engineering professions appears to be that the compensations should be more nearly parallel.

It is not to be supposed that a young consulting engineer or geologist, just out of college or from a government survey, can expect as good fees as after obtaining a broad experience covering many years. Yet, there is no doubt that the fees which we

receive for high-grade work are in most cases too low. A lawyer who collects a debt will charge from one tenth to one fourth of the amount collected; an architect who plans a house will charge from 5 to 12 per cent. Why should a geologist who locates an oil pool receive any less proportion of the amount involved?

There seems to be a popular aversion to paying professional fees. Many companies prefer to locate and drill wells on a "hunch" of their superintendents or managers, some employ "oil smellers" or "quacks," who, for a paltry fee, will locate a well with their forked stick or "magnetic" instrument, while others will search the ranks of geologists and pseudo-geologists until he finds the cheapest of all. No wonder dry holes based on geologic advice are many, and that oil-men have frequently been loud in their condemnation of geologists and of expert advice. If nothing but experienced men of broad judgment were employed as experts, our profession would be much more appreciated, and our fees would be commensurate with the real value of our advice. Taking into account the value of our time to the community and to the oil business as a whole, we believe there is little justification in small fees; and that it is legitimate for a high-grade expert to charge what the business is worth to his client.

VI. THE QUESTION OF PROMOTIONS.

The question of whether a mining engineer may legitimately engage in promotions has been often asked, and was revived in the *Engineering and Mining Journal* of May 24, 1913. We agree with Mr. Wm. B. McKinley[26] that

> "For the mining engineer whose reputation is free from the slightest stain and whose professional or business honesty has never been questioned, the promotion of engineering enterprises on a rational basis is a perfectly legitimate field."

If the geologist be strictly a professional man, he will decline to partake in any promotion, even in territory which he may find

[26] *Eng. and Min. Jour.*, Vol. 96, 1913, pp. 415-416.

promising. If, on the other hand, he be strictly a promoter, he will decline to examine properties or make appraisals for a mere fee. Between these two classes of geologists is the middle class who act as professional advisers and also delve in promotions. In the business of promoting a few have succeeded, some have failed, and many have dropped back into the ranks of strictly professional men.

As a matter of fact, it is not ethically wrong for a geologist to search out a promising field in a region where he is without professional ties, and to find capital for developing it. If, however, the field be in a region where he has previously made a professional report, he is under first obligations to offer the territory to his client. If he be financially interested in a promising lease, and later accept an offer to report to a client on adjoining property, *he is still in duty bound to give his client the first chance.* Probably the client would never ask him to make the report if he knew of the geologist's property nearby; and, at any rate, he is continually open to the suspicion of acting or reporting unfairly. For these reasons, a geologist must always keep himself above suspicion in his acts and motives.

Unfortunately few of our profession now remain who adhere to the elementary principle of aloofness from taking an "interest" in an oil property; but it is important for the good of the profession to do this just as little as possible; and, if done, it should be without secrecy. A strict adherence to this principle will generally result in an ultimate advantage to the geologist. An illustration may be helpful, viz.:

Previous to his first trip to Mexico, the writer incidentally apologized for his inexperience in that country, at the same time fearing that his confession might result in not receiving the commission. His client replied, however: "That is just why we want you. In this proposition it is important to have an expert who is entirely unbiased as to results expected." If that be the attitude in a foreign country, how much more must it hold in some of our own oil fields where hundreds of different owners have leases within a few miles?

In short, a professional geologist should not take part in promoting any ordinary proposition (there are plenty of men who will do so); but the day may come in which he knows that a certain field of great prospective value will not be developed by his clients or other parties, or not developed wisely; and he must do it himself in order to assure the success of the field. In some cases the duty of a petroleum geologist, after making his report, is manifestly to turn promoter. For instance, a certain locality was once examined in detail with the object of finding the best route for a new railroad. The geological structure and other conditions, previously unknown, proved to be the very best, and so favorable as to render it desirable also for oil development. The geologist, in order to do his clients and the public full justice, was, with the permission of his clients, doing them a service by advising oil companies to enter and develop the field.

We are, throughout this discussion, endeavoring to consider the interests of the community and the profession equally with those of the geologist, and nothing deserves consideration here which renders the former subservient to the latter. Therefore, we must mention an additional advantage gained in certain cases by the geologist becoming a promoter. An untested field existed in which the competition would presumably be great. The land would be divided into small parcels and "line-fighting" would prevail, with the result that the expense of development to the community would be many times that of its scientific development by a company having a monopoly. The geologist, if he be an experienced engineer, knows these things in advance. He also knows that gushers will be obtained in the development of that field; thus tempting unscrupulous and inexperienced promoters to organize stock-companies without proper backing or management and which will result in losses to their stock-holders. All this can be avoided by a proper control of sufficient territory and by its management by experienced parties. In such a case, the conscientious geologist may feel bound by duty to promote and manage this proposition himself in order to secure development that will result in an economic gain instead of a loss to the community.

Not only from the standpoint of the individual, but also from that of the community, therefore, we see that in certain cases the geologist can legitimately become a promoter. We must, however, clearly distinguish and teach the public to distinguish between bona fide and pseudo-geologists. Unfortunately, many men are roaming the country, who, without suitable geological experience or knowledge, write a kind of report on properties; then, calling themselves "geologists," approach financiers with these in hand, and delude capital into unwise investments. It behooves us, as geologists, understanding the differences between true and false experts, to consider whether or not there is any way of ridding the profession of these "hangers on," many of whom are without the beginning of a geological education or training.

A consulting geologist will often be approached by persons with land, leases, mines or mineral rights for sale. He will be asked whether some of his clients will be interested in the particular speculation involved. Only two courses appear to be open to the conscientious specialist: *First,* to recommend having a geological and engineering report made, adding, if desirable, the statement that this is necessary in order to prove the value of the property to his clients; or, *secondly,* to decline absolutely to have anything to do with the proposition. *No other course appears to be fair to his own practice or to other members of the profession.*

VII. THE MATTER OF OFFICES.

Another cause has operated to drive reputable consulting geologists into the promotion and operating side of the oil business, viz.: the fact that some of the profession are connected with educational and other institutions. The professional practice of bona fide professors is discussed by a writer who signs himself "Consulting Engineer" in the *Engineering News* of Feb. 11, 1913 (Vol. 73, pp. 276–277), who remarks that

"The professor can afford to name a lower price, because he . . . is at no expense for equipping and maintaining a laboratory, since he

makes use of the facilities afforded by the university. Office rent, and the hire of stenographers, clerks, etc., which the private engineer has to bear, involve no expense to the professor of engineering; and there are cases where he has utilized students to aid him in his professional work, paying them a nominal compensation or none at all."

We cannot agree with "Consulting Engineer" in his implied condemnation of bona fide professors in professional practice, since their salaries are small in most cases; their outside professional work better fits them for their teaching, and frequently their contract permits them to do outside work. We know, however, that in the profession, there are some men who become merely parasites on a university, giving little or no real instruction; but getting their names into the catalog for the purpose of advertising, securing free office rent, or of allying themselves with professors of greater ability and integrity. This practice is to be condemned.

We should, therefore, in justice to other members of the profession, insist on a certain ethical stipulation, viz.: that the universities and schools should not allow a professional man to use them simply for advertising purposes, as has been done in some cases. A geologist should not be allowed to advertise himself as lecturer in an institution, or to maintain his offer there, unless he be a bona fide member of the instructing staff, giving material time to its welfare; or, in a few cases, if he be a retired professor, who having given years of valuable service to the institution and the profession, is in return granted special office privileges. Any other procedure is injurious to the reputation of the institution, as well as to the individual and to our profession.

VIII. THE MATTER OF REPORTS.

Geological reports are of various classes, oral, telegraphic, by letter, and in bound and sometimes printed form. They range in length from the simple cabled words "Favorable" or "Unfavorable" to hundreds of pages and maps of large size. The chief aim of our existence is to render satisfactory and valuable

reports. If these save money to our clients, or enable an increase of profits, we have achieved our object. Consequently, it is of greatest importance that we make these reports definite, concise, and authentic. We must make them the foremost authorities on the subject in hand; and sufficient in all respects for the purpose desired, regardless of whether we personally profit or lose by them. We will assume that the accuracy of our field-work has been commensurate with its object; and in such a case it is not difficult to render the accuracy of the report likewise, to include all causes that should be included and omit everything which should be omitted.

Having then a model report, we must make sure of its adherence to professional ethics. Nothing must be included that is the property of a competitive client without that client's express permission. The report should cover the ground thoroughly, while without injuring the interests of adjoining clients. We must then proceed to maintain this report as forever confidential, not allowing it to become known to other parties. The same statement applies to data which are the property of a client; they should be maintained in strictest confidence.

SUMMARY.

The foregoing are a few matters of professional ethics about which questions may arise in the experience of the petroleum geologist. Some of these can be easily answered by the individual; but others will be pondered for years before a decision is reached. Some questions concern only our own consciences, while others are of great importance to our associates, to our clients, and to the community. Under the most favorable circumstances, differences of opinion and pertinent questions will arise; and it is with this thought in mind that it seems wise to discuss the subject publicly for the purpose of enlightenment and for serving as a guide in the future practice of our profession.

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GENESIS OF THE SUCCESS ZINC–LEAD DEPOSIT, COEUR D'ALENE DISTRICT, IDAHO.[1]

JOSEPH B. UMPLEBY.

Introduction.—Fundamental to a correct conception of the genesis of the Coeur d'Alene ores is an understanding of the Success, formerly the Granite deposit. From the type of ore found to be closely related to an igneous contact, Ransome[2] has traced, by mineralogical gradation, a close correlation with deposits well removed from any known granitic mass, and concluded that the ores of the district are genetically related to the monzonite widely exposed in Idaho. Hershey,[3] on the other hand, believes that the deposit was formed prior to the monzonite intrusion and was invaded and metamorphosed by it. This conception is in accord with his hypothesis that the Coeur d'Alene deposits have been concentrated from invisible disseminations of lead and zinc in the Prichard formation.

The object of this paper is to cite evidence collected by the writer, assisted by E. L. Jones, Jr., during his examination of the mine in June, 1916, incident to a general report on the ore deposits of Idaho. The principal conclusions resulting from this work are: (1) the deposit is of contact metamorphic origin, differing only from most deposits of this type in that the metamorphosed rock is siliceous slate and quartzite instead of limestone; (2) the metamorphism took place, at least in large part, after the solidification of the igneous rock adjacent which is locally replaced by metamorphic minerals, and (3) a poorly de-

[1] Published with the permission of the Director of the United States Geological Survey.

[2] Ransome, F. L., and Calkins, F. C., "Geology and Ore Deposits of the Coeur d'Alene District, Idaho," Prof. Paper U. S. Geol. Survey No. 62, p. 136, 1908.

[3] Hershey, O. H., "Origin and Distribution of Ore in the Coeur d'Alene," pp. 16–19. Published at private expense by *Mining and Scientific Press,* San Francisco, Cal., 1916.

fined zone of shearing which accompanies a biotite schist member of the Prichard formation, directed the metamorphosing solutions. That the ores are a little younger than the monzonite is shown by: (1) pyrite and sericite, minerals intimately associated with the sulphides, are extensively developed in the monzonite, the former principally after hornblende and the latter after feldspar; (2) sphalerite, galena, magnetite and lime silicates intergrown with them, replace the monzonite in several places; (3) the same sulphides occur as veinlets in monzonite in at least five other deposits of the district, and (4) the ore bodies in places traverse dikes of the monzonite as on the 300-foot level (Fig. 2).

Geologic Relations.—The Success mine, situated on the East Fork of Ninemile Creek about 5 miles north of Wallace, is in the central part of a narrow tongue of Prichard slate and quartzite which extends eastward for nearly a mile into the monzonite mass west of Gem. In the vicinity of the mine the sedimentary beds are metamorphosed to biotite schist, micaceous quartzite and dense greenish quartzite, each type containing variable amounts of garnet, pyroxene, biotite, muscovite, and locally chlorite and epidote. The structure of the beds is in many places difficult to decipher, but in general they strike northwest and dip southwest from 30 to 85 degrees. The Prichard rocks are intricately traversed on nearly all of the thirteen levels of the mine by tongues and dikes of the monzonite, as is well illustrated on the 300-foot level (Fig. 2). In places the monzonite apophyses are traversed by the ore as is clearly shown between stations 300 and 308 on this level, where a 10-foot dike nearly at right angles to the course of the ore body is exposed in opposite sides of the stope at a point where ore was extracted to a width of about 12 feet. Another equally clear example of ore formed subsequently to the monzonite appears on the same level near station 324, where an offshoot from the main ore body replaces a 4-foot dike and extends into the quartzite beyond.

On the 100-foot level, 191 feet above the 300, the ore body, retaining its width of 3½ to 5 feet, crosses a southwest-dipping monzonite dike. This relation continues for 60 feet below the level but from there down no ore has been found in the monzo-

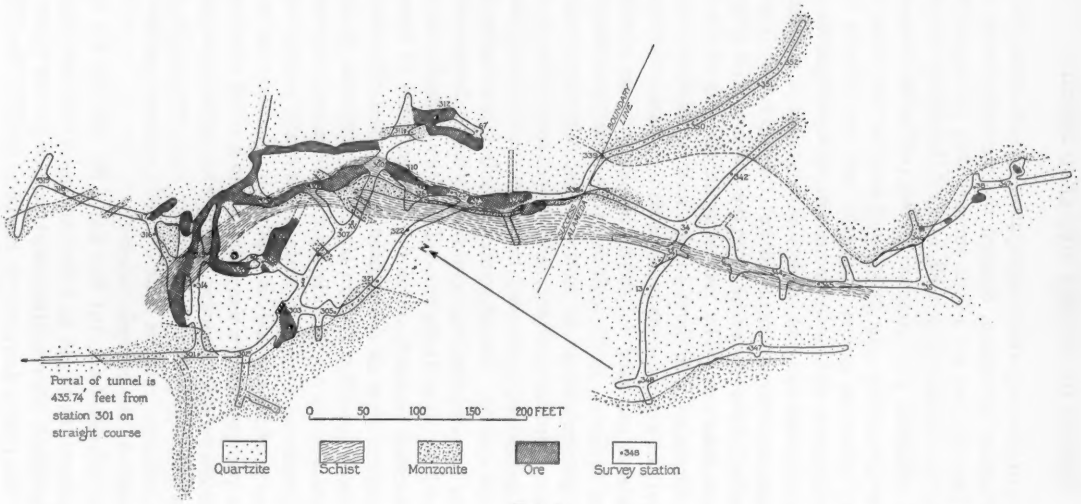

FIG. 2.

Geologic map of the 300-ft. level, Success Mine, Coeur d'Alene District, Idaho. Geology by J. B. Umpleby and E. S. Jones, Jr.

nite, although it has been mined in the adjacent quartzite for more than 100 feet further down. Above the level the stope continues between granite walls for 40 feet without diminution in width. As there is notably less fracturing within the dike than beyond it, the relations are interpreted as: (1) shearing, (2) intrusion of the dike, and (3) renewed shearing accompanied or followed by replacement of wall rock, whether quartzite or monzonite, by ore.

The relations below the 100-foot level described above suggest that the quartzite was more easily replaced by the mineralizing solutions than the monzonite which is clearly shown by hand specimens to have been locally replaced. This suggestion is borne out by the deposit as a whole, for, although the monzonite has been intensely altered in places, the total volume of it which has been replaced by ore, compared with the other rocks, is negligible. Of the several types of rock in the mine, most of the ore is inclosed in mica schist, a notable amount in the micaceous quartzite, very little in the dense greenish quartzite, and still less in the monzonite.

Distribution and Form of the Ore Bodies.—The distribution of the ore bodies is controlled by the shearing planes of the biotite schist, although by no means confined to them. This member of the Prichard, from 10 to 20 feet thick, strikes a little west of north in the southeast part of the mine but to the north turns abruptly westward and terminates against the monzonite in the vicinity of the shaft. Here it dips about 80 degrees southward but gradually flattens toward the southeast to a dip as low as 45 degrees.

The ore occurs in lenses in the biotite schist and in the micaceous quartzite above and below it. The lenses attain their maximum development near the bend in the formation and here an outer and inner series occur; the former principally in the schist and the latter in the overlying micaceous quartzite. Westward the ore abuts the monzonite, extending into it a short distance in places, but southeastward the mineralization dies out through a series of isolated lenses on the same general zone. Most of the lenses in the productive part of the zone are connected either by

merging in places along their periphery or by oblique or transverse bodies. Thus if a stope sheet were made by projecting the worked parts of the deposits to a common plane, the ore body would appear as a vein. On the other hand cross sections and plans of separate levels bring out the essential characteristics of the irregular replacement phenomena controlled by the distribution of a zone of shearing in the comparatively thin biotite schist member of the Prichard formation.

The principal ore body was found on the curved part of the zone and worked continuously from the surface to the 1,200-foot level. It was largest on the 500 level where the sill floor was 60 by 100 feet; above and below it ranged from 125 to 235 feet in length and from 16 to 18 feet in width.

Within the lenses there are many residual masses of country rock locally giving faces the appearance of a sulphide-cemented breccia. Elsewhere great isolated blocks or "horses" occur in the ore bodies. In most places these are mined as a necessity of the shrinkage system employed, but elsewhere they stand in stopes now worked out. That the ore is due to replacement and is in no sense a fissure or breccia filling is very clear to the writer and is one of the characteristic features of the deposit. He can not agree with the statement of Hershey[4] that "the ore is in a vein and spurs" or that in "general character it is like the fissures of the Prichard type vein at a distance from the granite." The veins in the Prichard occur irrespective of the attitude of the beds and in most places transgress them at high angles. Here, on the other hand, the evidences of selective replacement along the course of a particular type of rock, the biotite schist, is most striking. Along this course there is no evidence of fissuring but instead a distinct schistosity, perhaps accompanied by some shearing, parallel to which most of the ore lenses are oriented. Wider parts of the ore bodies in many places extend beyond the limits of the biotite schist into the micaceous quartzite above and below, and locally lenses of considerable size occur many feet beyond the limits of the schist.

The Ores.—The ore from the mine, extracted by a shrinkage

[4] *Op. cit.*, p. 17.

system without sorting, contains from 8 to 10 per cent. zinc, 2 per cent. lead, and about 1½ ounces of silver to the ton. Sphalerite is the dominant mineral but magnetite, pyrite, galena, and quartz are present in most places. The characteristic gangue is quartzite or biotite schist replaced to a greater or less extent by lime silicate minerals. The sulphides are distributed throughout an ore body in blebs, bunches, lenses, and connected areas of ramifying habit. The galena clearly formed later than the sphalerite which it traverses as veinlets and connected patches. Pyrite is scattered through the sphalerite in isolated crystals or small groups of crystals and may be contemporaneous with it. It is noteworthy, however, that the pyrite extends into the surrounding rock much further than the sphalerite, in the case of the monzonite, replacing the hornblende to a distance of at least 200 or 300 feet from any known ore body. Magnetite is intimately associated with the sphalerite and may be nearly contemporaneous with it although in one of the specimens studied it is distinctly older.

Sericite is associated with the sulphides irrespective of whether they replace quartzite, schist or monzonite. In the quartzite it occurs as veinlets cutting the quartz grains, and interstitially between them; in the schist as flakes parallel to the schistosity; and in the monzonite as isolated flecks and felted aggregates in feldspar areas, and as veinlets. A pleochroic carbonate with the low index higher than Canada balsam but much lower than siderite, and hence probably a ferruginous calcite, accompanies the sericite in one of the specimens. Where a veinlet of calcite intersects one of sericite the latter invariably cuts the former and where the two minerals occur in the same veinlet the sericite occupies the medial plane. Quartz occurs both in veinlets cutting the ore and in microscopic intergrowth with the several sulphides.

Silicate minerals occur in much of the ore in microcrystalline individuals and aggregates closely intergrown with the sulphide minerals. In the monzonite, garnet, pyroxene (probably hedenbergite), a blue amphibole, epidote, chlorite and rarely tourmaline, occur in minute microscopic grains. Garnet is the prevalent contact mineral in the quartzite and schist, but epidote, diopside,

and chlorite are present in most places in variable amounts. The intimate intergrowth of the silicate minerals and the sulphides is shown in Figs. A and B.

Metamorphism.—Unlike contact zones in limestone there is here no sharp line of demarkation between rock clearly of metamorphic origin and unmetamorphosed material. All of the invaded rocks are aphanitic. Where metamorphism is intense the texture is little changed, and color, combined with a slightly increased specific gravity is the principal suggestion that transformations have taken place. Where garnet is the principal metamorphic mineral the color is either pink or light amber; if a pyroxene, it is greenish, as is also the case where epidote is abundant. Minor amounts of these minerals, however, do not affect the normal gray or greenish gray color. The product of intense metamorphism of the monzonite is a rock somewhat resembling the intensely metamorphosed quartzite but in most places retaining sufficient of the monzonite pattern to be easy of identification. It also has a dull appearance due to advanced alteration in feldspar areas. Thus within the deposit two common types of metamorphism are recognized; exomorphism, or the transformation of the invaded rock, and endomorphism, or the metamorphism of the intrusive rock. These phenomena will be described separately.

Exomorphism.—The Prichard rocks throughout the mine have been "completely recrystallized to an aggregate of interlocking quartz grains which inclose variable proportions of pale-green monoclinic pyroxene, green-brown biotite, white mica . . . and garnet."[5] Although the metamorphism is general throughout the tongue of slate and quartzite which extends into the monzonite, it is particularly noteworthy that different beds have been affected differently. Garnet is most abundant in the fine-grained, greenish quartzite which occurs principally in the eastern part of the mine. Sericite is conspicuously developed in the micaceous quartzite above and below the schist and to a less extent in the other rocks. Diopside occurs principally in the biotite schist. Tourmaline appears in one of the slides of greenish quartzite.

[5] Ransome, *op. cit.*, p. 185.

The biotite in the schist and the muscovite in the adjoining quartzite are oriented parallel to the foliation and probably formed in principal part incident to the shearing stresses causing the development of schistosity. The lack of shearing within the monzonite where it truncates these beds affords the conclusion that the development of the schistose zone, and the biotite and muscovite incident thereto, antedate the intrusion. The development of the sericite, garnet, pyroxene and epidote, however, is a distinctly later phenomenon. These minerals occur in irregular bunches, veinlets, and ill-defined patches connected by stringers of similar material. Their general distribution is controlled by the zone of shearing, but in many places they lie athwart the foliation whose planes terminate abruptly against them as against the sulphide bodies.

The areas of moderate metamorphism are more extensive than those of replacement by ore but areas of intense metamorphism, areas in which lime silicates comprise 50 per cent. or more of the mass, seem to be much more limited than the ore bodies. The rocks are more intensely metamorphosed in the east end of the mine than elsewhere but most of the ore occurs in the west end.

The essential contemporaneity of the sulphides and silicates is proved by specimens from several parts of the deposit and abundantly bears out Ransome's conclusion[6] that "the association of the ore minerals with the metamorphic silicates is so close that the conclusion of their contemporaneous genesis is unquestionable." In a few places (Fig. B) the sulphides form veinlets in the metamorphosed rock suggesting that the sulphide deposition continued after the cessation of lime-silicate development. The relation, however, is believed to be exceptional, although the amount of material available for microscopic study does not warrant a definite conclusion. The deposit is not favorable for paragenetic studies without the aid of the microscope, as the contact metamorphic rock in most places is megascopically uncertain of identification and impossible of classification. The metamorphic silicates in most specimens occur in exceptionally minute grains, a magnification of from 50 to 250 diameters being necessary to

[6] *Op. cit.*, p. 185, and Plate 98.

EXPLANATION OF PLATE V.

FIG. A. Pyrite and galena (black) as bunches, veinlets, and intergrowths in a garnet pyroxene rock developed from quartzite. Quartz (white) and calcite (light gray) occur along one side of the section. × 35.

FIG. B. Garnet and related lime-silicates (gray) intergrown with sphalerite, galena and gamnetite (black). The original rock was monzonite traversed by an aplite seam, the quartz of which (white) is preserved in the left one half of section. × 35.

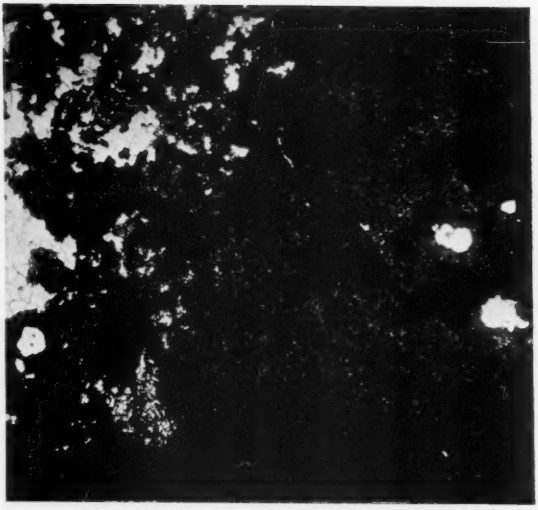

FIG. A.

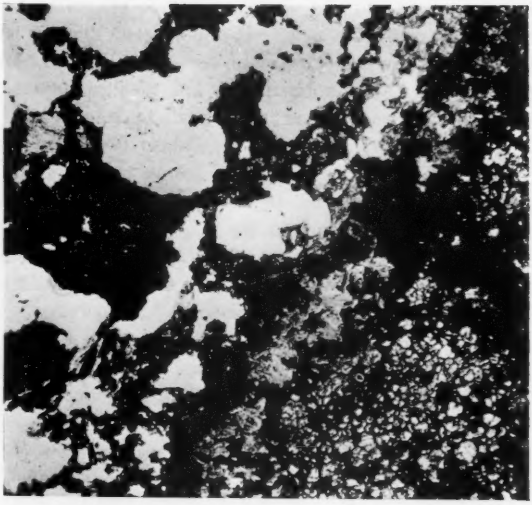

FIG. B.

the recognition of separate crystals. Interlocking with these in low-grade ores are equally small grains of sphalerite, pyrite and less often galena.

Endomorphism.—The most interesting result of the recent investigation of the deposit is the recognition for the first time of clear evidence of endomorphism. The monzonite in many places in the mine has been changed from a fresh hornblende-bearing rock into an intensely sericitized pyrite-bearing rock, and locally into an intimate intergrowth of sulphides and metamorphic silicates. This conclusion is opposed to that of Hershey[7] who states that "most of them (the sulphide patches in monzonite) . . . have fragments of schist attached, indicating that they are inclusions" and thus are not discordant with his general proposition "that the veins are older than the intrusion of the adjacent monzonite." It agrees in general with the view of Ransome[8] who states that "the ore . . . was deposited shortly after the intrusion of the monzonite and is a phase of contact metamorphism." His observation, however, based upon relations as exposed in 1904, that "the ore is strictly confined to the sedimentary rock," now requires modification.

The diversity of opinion of the previous writers as to the relative ages of the ore and the monzonite justifies a rather complete assembling of the evidence for the writer's conclusion that the metamorphism and metallization were subsequent, not only to the injection of the magma, but to the chilling and solidification of its outer part.

As previously stated and as illustrated in Fig. 2, it is clear that ore bodies cut apophyses of the monzonite and clearly are of later development. This is abundantly borne out by the evidence of hand specimens, thin sections, and polished surfaces. Fig. C is a photograph of a specimen showing not a vestige of included sedimentary rock. It consists of sphalerite, pyrite, and galena, in a gangue of metamorphosed monzonite, in which magnetite is locally abundant. Thin sections, Fig. B, clearly prove the essential contemporaneity of the metamorphic silicates and sulphides.

[7] *Op. cit.*, p. 18.
[8] *Op. cit.*, p. 185.

EXPLANATION OF PLATE VI.

FIG. C. Monzonite partly replaced by sphalerite (sp), galena (G), pyrite (P), magnetite (part of black area) and lime silicates after injection of an aplite seam shown at B and in figure B. Thin sections were cut at A. B. C. and D. From near shaft 860-foot level, Success Mine. 9/10 natural size.

FIG. D. Sphalerite, galena, and pyrite replacing monzonite (light). Success Mine, 300-foot level. 8/10 natural size.

FIG. E. Galena and chalcopyrite (black areas) replacing syenite. From the Lilly prospect, Coeur d'Alene District, Idaho. 8/10 natural size.

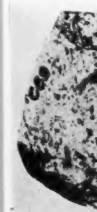

FIG. C.

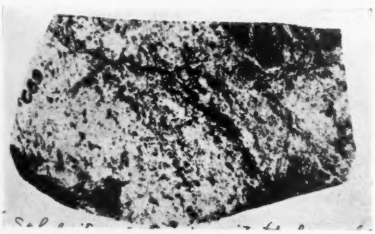

FIG. D.

FIG. E.

In one part of the specimen an aplite dikelet cuts the monzonite and is itself cut by a seam of pyrite, magnetite, sphalerite, and galena. Throughout part of its extent magnetite, sphalertite, and galena are collected along its contact with the inclosing rock. In many parts of the specimen the sulphides have irregular replacement contacts against the monzonite which is cut locally by minute veinlets of the sulphides. Thin sections were made from the other part of the specimen at points corresponding to *A, B, C,* and *D,* indicated in the figure. Thin section *A* consists of andradite, a green and blue pleochroic amphibole, hedenbergite, sphalerite, pyrite, magnetite, galena, and locally quartz. The silicates and sulphides occur predominantly in interlocking grains but in a few fields sphalerite and galena form veinlets. Section *B* (Fig. B) consists of an intergrowth of garnet, hedenbergite, green and blue pleochroic amphibole, galena, sphalerite, pyrite and magnetite, decreasingly abundant, traversed by an aplite seam made up of quartz, with amphibole, pyroxene, garnet, and sericite in the feldspar areas. Section *C* is made up of minute interlocking crystals of garnet, blue-green amphibole,[9] hedenbergite, sericite, biotite, olivine, and chlorite. The slide from point *D* is of much less altered monzonite. In it feldspar comprises perhaps 80 per cent. of the mass. Sericite is the dominant alteration product occurring in seams, flecks, and patches in both orthoclase and plagioclase areas. Chlorite occurs in seams and with what appears to be iron oxide in areas corresponding in distribution to the hornblende of the fresh monzonite. Sphalerite occurs in seams and with pyrite along one edge of the section.

The above specimen was taken in a stope from the 860-foot level, but others equally conclusive of metamorphism and ore deposition after marginal solidification of the monzonite were collected from the 100, 300 (Fig. D) and 1,000-foot levels. Several other deposits in the Coeur d'Alenes show similar characteristics, although in most of them the monzonite is fresher. In the American prospect, immediately west of the Success mine, quartz

[9] The amphibole is optically +, has + elongation, extinction to 30 degrees and is strongly pleochroic in *X* yellowish to greenish, *Y* yellowish-blue, and *Z* blue tones.

and galena seams traverse monzonite in which sericite, chlorite, and pyrite are developed. Relations more like those at the Success mine occur in the Clark mine on Sunset Peak, in the Frisco mine at Gem, and in the Lilly and the Nellie Pollar prospects east of Murray. The ore at the Lilly prospect, consisting of galena with associated chalcopyrite, occurs as a replacement of syenite (Fig. E) adjacent to a 2-inch clay seam which separates it from Prichard slate. The bunches and seams of sulphides are most numerous next to the gouge seam, but they are present in diminishing numbers to a distance of 20 feet from it in two crosscuts 65 feet apart. The gouge is post-mineral.

The suggestion has been made that more than one period of magma injection is represented by the granitic rocks of the region and that the metamorphism accompanied the non-hornblendic type which is the older.[10] The specimen illustrated in Fig. C is of the hornblendic variety from the Success mine. The Lilly specimen (Fig. D) is of the syenite or non-hornblendic variety. It is clear, therefore, that the sulphides were deposited after the intrusion of both varieties of granitic rock. For this reason any difference in age of the two does not affect the present problem. It may be doubted, however, whether more than one period of granitic intrusion is represented by the rocks of the region. After a summary of the evidence Calkins[11] states:

"The conclusion drawn . . . is that the porphyritic syenite formed as a somewhat heterogeneous marginal segregation along the southern edge of the principal plutonic mass, and that it was broken up and intruded by the monzonite, perhaps before being solidified."

During the writer's 1916 field season nothing was seen which opposes the conception of one general period of magma injection.

SUMMARY AND CONCLUSIONS.

The essential contemporaneity of silicates characteristic of contact metamorphism and the sulphides is obvious from the thin sections illustrated in Figs. A and B. Garnet, pyroxene, amphi-

[10] Hershey, *op. cit.*, p. 19.
[11] *Op. cit.*, p. 46.

bole, epidote, and some of the sericite occur in interlocking relations with sphalerite, pyrite, and galena, so definitely that there can be no reasonable doubt that they are all products of the same metamorphic activity. Selective metamorphism characteristic of contact deposits is well illustrated in the different sedimentary rocks, most of the ore occurring in the biotite schist and micaceous quartzite members and comparatively little in the dense greenish quartzite and monzonite.

Sulphides and magnetite together with metamorphic silicates replace marginal parts of the monzonite and locally ore bodies cut across offshoots from the igneous mass. The monzonite in places is transformed from a medium gray rock consisting of orthoclase plagioclase (Ab 75, An 25), and brown hornblende, into a dull greenish mass made up of quartz, sericite, chlorite, pyroxene, amphibole, epidote, garnet and rarely tourmaline, in varying amounts, along with residual masses of the monzonite minerals. Sulphides may or may not be present in the metamorphosed monzonite but magnetite occurs in most of it.

Pyrite is widespread in the deposit but pyrrhotite has not been found in any of the material collected. This is worthy of note on the assumption that the deposit represents a vein invaded and metamorphosed by the hornblende monzonite, for it has been repeatedly observed that in contact-metamorphism pyrite is changed to pyrrhotite.[12]

The deposition of ore subsequent to the monzonite invasion is also shown in several other deposits of the region, and the relation is the same whether the rock be the hornblendic or the non-hornblendic variety. Specimens similar to those herein illustrated and allowing of but one interpretation, were collected from five widely separated deposits. Not all of them show such intense

[12] Brauns, R., *Neues Jahrb. f. Min.*, p. 373, 1913.

Backe, H. E., "Grundlagen der physikalisch-chemischen Petrographie," p. 282, Berlin, 1915.

Allen, E. T., Crenshaw, J. L., and Johnson, John, *Am. Jour. Sci.*, Vol. 33, p. 214, Mar., 1912.

Rosenbush, H., "Physiographie," Band II, Massige Gestine, p. 111, Stuttgart, 1907.

metamorphism as occurs in the Success mine, but all contain sulphides in seams and bunches in the monzonite.

One of the noteworthy features of the deposit is the extent to which a thin, steeply-dipping bed of biotite schist has directed the metamorphosing solutions. In many places, however, ore bodies expand well into the micaceous quartzite which lies above and below it, and locally considerable bodies of ore occur many feet beyond its limits.

The evidence discussed herein leads to the conclusion that the Success deposit was formed after at least the marginal solidification of the monzonite; that it is a normal type of contact deposit except for minor differences due to the quartzitic composition of the metamorphosed rocks and the distribution of a thin bed which has proved more susceptible of replacement than the other formations; and that, for reasons which follow it should be compared with such deposits as Velardeña,[13] Dolores,[14] Silverbell,[15] Mackay,[16] and Whitehorse,[17] in point of genesis. In each of these districts the lime silicates and sulphides are intimately intergrown and in places replace the igneous rock. The ore deposits of each of them have been considered as due to differentiates from the partly solidified intrusive. In the Mackay deposit particularly favorable relations make it susceptible of rigorous proof that the magma supplied most of the material of the ore and associated contact silicates, and in each of the others the evidence points strongly in the same direction. Considered as a group and in the light of their collective evidence, there can be little room to doubt that each of the deposits is due to magmatic emanations which escaped, in large part at least, after the mar-

[13] Spurr, J. E., and Garrey, G. H., "Ore Deposits of the Velardeña District, Mexico," ECON. GEOL., Vol. 3, pp. 688–725, 1908.

[14] Spurr, J. E., Garrey, G. H., and Fenner, C. N., "Study of a Contact Metamorphic Ore Deposit: The Dolores Mine, at Matehuala, S.L.P., Mexico," ECON. GEOL., Vol. 7, pp. 444–484, 1912.

[15] Stewart, C. A., "The Geology and Ore Deposits of the Silverbell Mining District, Arizona," *Trans. Am. Inst. Min. Engrs.*, Vol. 43, pp. 240–290, 1912.

[16] Umpleby, J. B., "The Genesis of the Mackay Copper Deposits, Idaho," ECON. GEOL., Vol. 9, pp. 307–358, 1914.

[17] McConnell, R. G., "The Whitehorse Copper Belt, Yukon Territory," Canada Geol. Survey, No. 1050, 1909.

ginal solidification of the magma. The Success deposit resembles these in the kind of metamorphic silicates developed and their relations to the sulphides; in the age relationship of the ore minerals and the solidification of the igneous rock adjacent, and in the distribution of ore bodies, except as modified by a thin bed particularly susceptible of replacement.

Few deposits considered alone afford conclusive proof of their genesis and in this particular the Success mine is not unique. It has been shown that in all essential points it accords with the criteria of contact metamorphic replacement deposits, and that in the sequence of events which have transpired in its development, it agrees with certain well-known members of that class. The alternative view that it is a replacement phenomenon later in age than the monzonite and related to it only remotely if at all, may be entertained by some students of the subject, but is strongly opposed by what is known of the genesis and geologic occurrence of the minerals characterizing the deposit. That the ore is not older than the monzonite is conclusively shown by field relations and by polished surfaces and thin sections of the monzonite described herein.

ORIGIN OF MASSIVE SERPENTINE AND CHRYSOTILE–ASBESTOS, BLACK LAKE–THETFORD AREA, QUEBEC.

R. P. D. GRAHAM.

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GENERAL GEOLOGY OF THE AREA.

The eastern townships of the Province of Quebec have for many years been the center of the world's asbestos (chrysotile) industry. The deposits occur within a discontinuous belt of basic igneous rocks, which are throughout their course altered, to a greater or lesser extent, to serpentine, for which reason they are generally referred to as the "*serpentine belt.*"

Up to the present time the main production of chrysotile has come from two separate centers along this belt, namely, Black Lake-Thetford and East Broughton. The mode of occurrence in these two areas is somewhat different; in the former, the material forms veins in which the fiber lies cross-wise, while in East Broughton it occurs almost entirely as "slip fiber" in which

thin layers of fiber lie parallel to the rock fractures. In the following pages an attempt is made to account for the formation of the massive serpentine and of the chrysotile in the Black Lake-Thetford area, and also to show the relation in which the two stand to one another.

For detailed information concerning the geology of the serpentine belt we are indebted mainly to Mr. J. A. Dresser, whose report[1] appeared in 1913, and the writer wishes to acknowledge the free use he has made, wherever necessary, of the data presented in this report.

The general geology of the area, as interpreted by Dresser, may be summarized as follows:

The serpentine belt consists of a series of igneous rocks of basic composition, which are intrusive through sedimentary strata of Palæozoic age. In the Black Lake-Thetford area, the latter are mainly upper Cambrian and lower Ordovician; further south, Silurian and early Devonian strata are also thought to be intruded, while to the north, in Broughton township, the igneous rocks appear to be older, though even here they were probably not intruded before late Cambrian time. Thus the rocks of the belt are principally post-Ordovician in age, and possibly they were intruded in Devonian time.

These igneous rocks include peridotite, pyroxenite, gabbro, diabase, porphyrite and hornblende granite, the latter sometimes passing into aplite; and the various types are all regarded as having differentiated from a single parent magma. The granite has usually been injected a little later than the other members of the series, and therefore in many places forms dykes and sills or intrusive sheets.

In the Black Lake-Thetford area, the igneous complex may be regarded as a batholith, exposed as a series of isolated stocks, and in these the different rock varieties are arranged in order of decreasing density and basicity from the center outward. Thus, as a result of truncation, their outcrop shows a central zone of peridotite, passing into the more acid rock types toward the

[1] Preliminary Report on the Serpentine and Associated Rocks of Southern Quebec, by John A. Dresser, Geological Survey, Can., Memoir 22, 1913.

margin. The serpentine gives its name to the belt owing to its economic importance, although actually it is the least abundant of the principal rocks of the series, occupying only small areas where the peridotite, and possibly also the pyroxenite, have been altered to serpentine.

MODE OF OCCURRENCE OF THE MASSIVE SERPENTINE AND CHRYSOTILE.

Detailed descriptions of the mode of occurrence of the massive serpentine and chrysotile-asbestos in the area may be found by referring to the report of Cirkel,[2] and, more especially, to that of Dresser. Some of the outstanding features may be briefly tabulated here. The most important points which have a direct bearing upon the genesis are as follows:

The massive serpentine occurs within the peridotite masses in the form of zones or bands whose boundaries against the peridotite are fairly well defined and are roughly parallel to one another, *i. e.*, they resemble dykes in outline and vary in dip from vertical to horizontal.

The more prominent bands fall into roughly rectilinear sets, which follow the same directions as the main system of joints in the peridotite. Others, which are in general narrower and more irregular in their course, intersect these and one another at all angles, so that in some places the peridotite presents a remarkably intricate network of such serpentine bands. Of these minor bands, Dresser believes some follow strain fractures due to regional compression, and others cracks caused by exfoliation.

The central part of these massive serpentine bands is usually occupied by the fibrous variety, chrysotile; this also is dyke-like in shape, *i. e.*, its boundaries against the massive serpentine are roughly parallel to one another and are rather sharply defined.

There appears to be a fairly constant relation between the total width of any massive serpentine band and of the chrysotile vein which it encloses. Attention was first called to this feature by Dresser, who, from a number of measurements (49), found that

[2] "Chrysotile-Asbestos, its Occurrence, Exploitation, Milling and Uses," by Fritz Cirkel. Mines Branch, Dept. of Mines, Ottawa, Canada, 1910.

the entire massive serpentine band is about 6.6 times as wide as the asbestos vein within it.

The chrysotile fibers are arranged parallel to one another, and extend transversely across the vein. Usually the fibers are not continuous across the vein, especially in the wider ones, but there is a parting, or sometimes more than one, at or near the center, which is occupied by a film of granular iron ore, usually magnetite.

There is an almost complete absence of carbonates, or of quartz, in the form of veins or otherwise, from the serpentine and associated rocks of the area.

Lastly, granite is frequently found in the vicinity of good asbestos deposits, or, an accumulation of asbestos veins (and therefore also of serpentine bands) can very frequently be noticed in approaching the granite dykes.

MODE OF ORIGIN OF THE MASSIVE SERPENTINE.

It is generally agreed that the massive serpentine has resulted from the alteration of the peridotite, and it is further believed that this metamorphism commenced along joint planes and other fractures, from which it proceeded outward in both directions. The main system of rectilinear joint planes is no doubt to be ascribed largely to the strains set up within the rock masses as they contracted on cooling, and along many of them dykes of granite were later injected. After a careful analysis of all the available field evidence, Dresser concludes that the magma from which the peridotite separated, underwent progressive differentiation until the last acid fraction had the composition of a granite, and he believes it is highly probable that the granite dykes are the visible expression of this final differentiate.

So far as the writer's observations go, these granite dykes are nowhere seen to intersect one another or to be cut by later igneous bodies, and it is probably safe to assert that, whatever their age, they are all contemporaneous and mark the latest phase of igneous activity in the area. Since Dresser cites one or two instances in the field where the granite occurs almost certainly as a direct

differentiation product, and in the absence of any evidence to the contrary, the dykes also are here assumed to stand in that relation to the peridotite and therefore to be separated by no very great time interval from the intrusion and consolidation of the latter. On this view, the formation of the joint planes and the injection of the granite dykes were more or less contemporaneous, and the change from peridotite to serpentine is thus correlated with the period of granitic intrusions, or some time subsequent thereto.

The field relations of the peridotite and serpentine so clearly and completely support the hypothesis that the latter has been produced by the alteration of the former, that this view may well be considered as an established fact; but with regard to the processes by which the change has been brought about there is by no means such clear and definite evidence, consequently the opinions held by different investigators vary. A discussion of the question naturally falls under two heads, one dealing with the nature of the reagents necessary to produce the metamorphism and the other with their source. At the outset, however, it is necessary to have a knowledge of the approximate chemical composition of the olivine contained in the peridotite, and also of the serpentine.

COMPOSITION OF THE OLIVINE AND SERPENTINE.

No analyses of the olivine contained in the peridotite are available but two analyses of the rock itself (dunite type), made by M. F. Connor, are quoted in Dresser's Report. These are as follows.

The large percentage of water, liberated only on ignition, indicates the presence in considerable quantity of some mineral containing water of constitution, and it is probably safe to assume that this is mainly serpentine. Removing the latter in the form of the compound $H_4Mg_3Si_2O_9$, which represents nearly enough its composition, it is found that the amounts of magnesia and silica remaining are approximately in the ratio 2 : 1, there being only a slight excess of MgO over this proportion. This might suggest that the olivine present is a nearly pure forsterite

Analyses of the Peridote and Calculated Mineral Composition of the Rock.

	%	Mol. Ratio.	$2H_2O.$ $3MgO.$ $2SiO_2.$	$2MgO.$ $SiO_2.$	$FeO.$ $Fe_2O_3.$	Not Used.	%	Mol. Ratio.	$2H_2O.$ $3MgO.$ $2SiO_2.$	$2MgO.$ $SiO_2.$	$FeO.$ $Fe_2O_3.$	Not Used.
SiO_2	38.16	.636	.535	.101		—	38.24	.637	.540	.097		—
Al_2O_3	0.63	.006				.006	0.70	.007				.007
Fe_2O_3	3.32	.020			.020	—	3.50	.022			.022	—
FeO	4.76	.066			.020	.046	4.25	.060			.022	.038
MgO	41.84	1.046	.802	.202		.042	41.92	1.048	.810	.194		.044
CaO	0.68	.012				.012	0.68	.012				.012
$(K, Na)_2O$	0.20	—				—	0.20	—				—
$H_2O - 110°$	0.47	—				—	0.60	—				—
$H_2O + 110°$	0.63	.535	.535			—	0.76	.540	.540			—
	99.69						99.85					
No. of molecules			.2675	.101	.020				.270	.097	.022	
			X	X	X				X	X	X	
Mol. volume			107.021	43.179	44.515				107.021	43.179	44.515	
Relative volumes			28.628	0.4361	0.0890				28.896	0.4188	0.0979	
Per cent. by volume			84.50	12.87	2.63				84.83	12.29	2.88	
Mineral			Serpentine	Forsterite	Magnetite				Serpentine	Forsterite	Magnetite	

($2MgO.SiO_2$) containing little or no iron, and that the latter metal is present in the rock mainly in the form of magnetite. The percentage mineral composition of the rock by volume, calculated on this basis, is shown above.

It should be added that the peridotite is not always so highly altered as these analyses would indicate, and Dresser[3] states that "the average rock of this locality is a peridotite consisting of 80 per cent. to 90 per cent. olivine"; but there is no reason for supposing that its iron content differs materially from that shown in the analyses above.

Some magnetite is certainly present in the rock as disseminated grains, and it is equally certain that a portion of the ferrous oxide is combined in the serpentine molecule. Assuming, however, that the whole of the ferrous oxide shown in the above analyses were present in the olivine, replacing its equivalent of magnesia, the mineral would then contain Mg : Fe nearly in the ratio 3 : 1. An olivine of this composition ($Mg_3FeSi_2O_8$) may thus be taken as the extreme limit which actually is never reached or even very closely approached.

The composition of the olivine might be roughly computed in another way, by assuming that the ferrous oxide which is left over, after eliminating the amount required to form magnetite, enters into the composition of the various minerals of the rock proportionately to the total magnesia. This gives the ratio Mg : Fe = .1046 : .046 or about 23 : 1, corresponding to $Mg_{23}FeSi_{12}O_{48}$. While this might be taken as indicating the limiting composition of the olivine in the other direction, it is probable that the assumption made is far from representing the true state of affairs, and that the olivine never approaches so closely to the composition of a forsterite.

Since magnetite grains can actually be seen scattered through the peridotite and serpentine, it is reasonable to suppose that the whole of the ferric oxide shown in the analyses of these rocks is present, combined with the necessary amount of ferrous oxide, in the form of magnetite. In the case of the first peridotite analysis given above (and the second is almost identical) we then

[3] *Op. cit.*, p. 59.

have 3.32 per cent. Fe_2O_3 united with 1.49 per cent. FeO to form $FeO.Fe_2O_3$, leaving 3.27 per cent. FeO to be distributed between the serpentine and olivine.

The amount of ferrous oxide required for the serpentine may be arrived at by considering the analysis given in column (1) below; this was made by M. F. Connor, and is reproduced from Dresser's Report.

	(1) Massive Serpentine Nr. Black Lake Station.	(2) Chrysotile Asbestos Nr. Black Lake Station.
SiO_2	40.08	39.62
TiO_2	None	——
Al_2O_3	2.11	0.81
Fe_2O_3	1.13	†4.52
FeO	1.70	1.90
MgO	*37.90	39.73
CaO	0.20	Trace
K_2O	0.10	Not detd.
Na_2O		Not detd.
$H_2O - 110°$	1.35	0.43
$H_2O + 110°$	13.89	13.32
	98.46	100.33

* Probably low. † Probably admixed magnetite.

The ferric oxide shown in the analysis (1.13 per cent.), assumed to be all combined in magnetite, will account for 0.51 per cent. FeO, so that the serpentine molecule itself contains 1.70 minus 0.51 or 1.19 per cent. FeO. The theoretical composition of such a serpentine, provided it conforms to the usual type ($H_4Mg_3Si_2O_9$), is as follows:

	Per Cent.	Mol. Ratio.
SiO_2	43.25	.535
MgO	42.58	.790
FeO	1.19	.012
H_2O	12.98	.535

In the last column are given the molecular ratios, reduced to the basis $H_2O = .535$ so as to be directly comparable with those in the other table. As will be seen, the ratio Mg : Fe is about 65 : 1, and the serpentine has the composition $H_{88}Mg_{65}Fe_1Si_{44}O_{198}$.

Reasoning in this way then, the ferrous oxide found in the analysis of the peridotite is apportioned as follows:

Per Cent.	Mol. Ratio.	How Combined.
1.49	.0207	in magnetite
0.88	.0122	in serpentine
2.39	.0332	in olivine
4.76	.0661	

The .101 molecules of SiO_2 which are assigned above to olivine are thus in combination with .0332 FeO + .1688 MgO = .202 (Mg, Fe)O; the ratio Mg : Fe = 5 : 1 and the olivine has the formula $Mg_5FeSi_3O_{12}$.

The assumptions made in arriving at this formula for the olivine of the peridotite are open to criticism, as also the fact that the whole series of calculations rests on the basis of a single analysis, in each case, of the peridotite and serpentine. However, as will appear, the iron content of the olivine, and in a lesser degree of the serpentine also, is a factor of some importance in considering the change of the former into the latter, and an approximate knowledge, at least, of the ratio Mg : Fe, especially in the olivine, is necessary before the probable course taken by the alteration can be intelligently discussed.

Summarizing, then, it may be said that the evidence on this point, so far as it goes, points to the average olivine of the peridotite as containing Mg and Fe in a ratio of the order 5 : 1; it would seem that this ratio never becomes as low as 3 : 1, while it may possibly be considerably higher than 5 : 1.

THE ALTERATION OF OLIVINE, AND OF PYROXENE, TO SERPENTINE.

If the olivine is very low in iron, *i. e.*, approaches forsterite in composition, there are apparently only two alternative processes by which the serpentine might have been formed. Since in forsterite the ratio Mg : Si = 2 : 1 and in serpentine 3 : 2, it is clear that the production of the latter from the former involves either an addition of silica (equation (1)), or a loss of magnesia. If the latter ensues, the excess of magnesia must enter into some new form of combination, and in the case under discussion the possibilities seem to be limited to the formation of carbonate or silicate (equations (2) and (2*a*)):

(1) $$3Mg_2SiO_4 + SiO_2 + 4H_2O \rightarrow 2H_4Mg_3Si_2O_9.$$

Increase in volume 40 per cent.

(2) $$2Mg_2SiO_4 + CO_2 + 2H_2O \rightarrow H_4Mg_3Si_2O_9 + MgCO_3.$$

Increase in volume 55 per cent.

The change in volume is calculated on the usual basis, using the molecular volumes which the original and resulting substances have at the ordinary temperature and pressure, and neglecting the volumes of liquid or gaseous substances which enter into the reaction.[4] In the case of equation (2), if the excess magnesia were removed, either as carbonate or in any other form, the expansion would be 24 per cent. instead of 55 per cent.

(2*a*) $$5Mg_2SiO_4 + 2SiO_2 + 6H_2O \rightarrow 3H_4Mg_3Si_2O_9 + MgSiO_3.$$

In the last equation, the MgO not required for the formation of serpentine is represented as entering into combination with SiO_2 to form $MgSiO_3$ (enstatite); as stated below however (equation (5)) it is probable that this molecule, if formed at all, would immediately react with one of Mg_2SiO_4 to produce, on hydration, more serpentine. The reactions (2*a*) and (5) combined are thus, so far as their end product is concerned, identical with reaction (1); they differ in that (2*a*) implies the production, momentarily perhaps but still continuously, of the molecule $MgSiO_3$. Its continuous formation and destruction during the change from forsterite to serpentine would be a little suggestive of the behavior of certain catalysers.

So far, the olivine has been considered as an iron-free variety. Supposing now that it is iron-bearing, it may chance that it already contains magnesia and silica in the exact proportions requisite for the formation of serpentine, without any addition of SiO_2 or removal of MgO. If its iron content separates in part or wholly as magnetite, it is necessary to presuppose the presence of oxygen in some available form, to convert a portion of the iron

[4] The molecular volumes used are those given by Van Hise ("A Treatise on Metamorphism," U. S. G. S. Monograph, Vol. XLVII.).

from the ferrous to the ferric condition. The following equation (3) represents such a reaction:

(3) $3Mg_3FeSi_2O_8 + 6H_2O + O \rightarrow 3H_4Mg_3Si_2O_9 + Fe_3O_4$.

Increase in volume 30 per cent.

This represents an olivine containing magnesium and iron in the proportion 3 : 1, a ratio which, according to the estimate made above, is never reached in the olivine of this area; and the resulting mixture of serpentine and magnetite would contain rather more than 12 per cent. of magnetite by volume.

An olivine of this composition might, however, conceivably give rise to serpentine in other ways, such, for instance, as the following:

(4) $3Mg_3FeSi_2O_8 + 3CO_2 + 4H_2O + O \rightarrow 2H_4Mg_3Si_2O_9 + Fe_3O_4 + 3MgCO_3 + 2SiO_2$.

The increase in volume is here 37.13 per cent., while if the $MgCO_3$ and SiO_2 are removed, there is a decrease of a little over 8 per cent.

Equations such as these might be multiplied indefinitely, by imagining olivines of different compositions to react with waters either free from or containing varying amounts of SiO_2 or CO_2, together with some form of available oxygen; and although an increase in volume is common to all such reactions when the total products are taken into account, they quite commonly show a decrease, as in equation (4), when carbonated waters are the reagent and only the serpentine and magnetite formed are considered.

While the reactions which might be postulated are thus innumerable, their final analysis reveals the following:

(1) An olivine which contains Mg and Fe in the ratio 3 : 1 might give rise to an iron-free serpentine by simple hydration (plus oxidation), without any addition or removal of either silica or magnesia; in such a case, the whole of the iron must separate as oxide, a part or the whole of it being oxidized to the ferric state.

(2) Olivines with $Mg:Fe = <3:1$, *i. e.*, containing more iron than the above, may similarly change to iron-bearing serpentines, by simple hydration plus oxidation, without any gain or loss of either silica or magnesia, *e. g.*, for $Mg:Fe = 1:1$,

$$3Mg_2Fe_2Si_2O_8 + 6H_2O + O \rightarrow 3H_4Mg_2FeSi_2O_9 + Fe_3O_4.$$

(3) *Olivines with $Mg:Fe = >3:1$, i. e., in which less than one fourth of the magnesium is replaced by iron, can on no account become altered into serpentine, either iron-free or iron-bearing, except by (a) the addition of SiO_2 or (b) the removal of MgO.*

The peridotite of the area is seldom or never made up entirely of olivine; it usually contains some pyroxene, and, with increase in the latter mineral, the rock passes over into pyroxenite, although it is true that in the Black Lake-Thetford area, good asbestos deposits (and consequently, wide serpentine bands) are found only associated with the peridotite. However, some pyroxene is commonly present, and this may be the orthorhombic variety, enstatite, or a monoclinic pyroxene, such as diallage.

Enstatite might react directly with forsterite to produce serpentine, as follows:

$$(5) \qquad MgSiO_3 + Mg_2SiO_4 + 2H_2O \rightarrow H_4Mg_3Si_2O_9.$$

Increase in volume nearly 50 per cent.

The possibility of such a reaction as this taking place is increased by the fact that when serpentine is fused it yields a mixture of enstatite and forsterite,[5] and there can be little doubt that this reaction follows the usual rule, and is reversible under suitable conditions.

Enstatite itself, of course, sometimes alters to serpentine, but being a more acidic mineral than the latter, the change must always be accompanied by the setting free of silica. An iron-bearing enstatite (or hypersthene) might give rise to serpentine, magnetite and silica by a reaction corresponding to (3) above, and, theoretically at least there might be a decrease, instead of an

[5] A. Daubrée, *Compt. Rend.*, Vol. 62, 1866.

increase, in volume accompanying the change, provided the silica set free is assumed to be removed; otherwise, as in the alteration of olivine, the final products always occupy a larger volume than the original mineral.

If carbonated waters are assumed as the agent which brings about the alteration of enstatite to serpentine, one half of the magnesia contained in the mineral must be set free in the form of carbonate, in addition to a loss of two thirds of its silica, and if these two substances were carried away in solution, there would be a decrease in volume of about 43 per cent. The reaction postulated would be like (6) below, substituting Mg for Ca.

In the alteration of olivine, or of enstatite, the whole of the base (magnesia) present in the original mineral may, under suitable conditions, be assumed to remain combined in the resulting serpentine (reactions (1), (3), (5)). The monoclinic, lime-bearing pyroxenes present a new feature, since all the lime they contain must necessarily enter into some new form of combination. The change is usually represented as taking place according to the equation

$$(6) \quad 3CaMgSi_2O_6 + 3CO_2 + 2H_2O \rightarrow H_4Mg_3Si_2O_9 + 4SiO_2 + 3CaCO_3,$$

which gives an expansion of more than 56 per cent.: if all the calcium carbonate is removed from the scene of reaction, there is practically no change in volume, and assuming the silica also to be carried away, there is a considerable shrinkage. If the pyroxene contained iron (diallage), it might give rise to an iron-bearing serpentine, or the iron, with partial oxidation, might separate as magnetite.

Theoretically, however, there is no reason why the calcium must necessarily be removed in the form of carbonate. It may be that, under the conditions which prevailed, heated waters alone were sufficient to break down the diallage molecule, and that the calcium was carried away in solution in the form of silicate, as indicated by the equation

$$(7) \quad 3CaMgSi_2O_6 + 2H_2O \rightarrow H_4Mg_3Si_2O_9 + 3CaSiO_3 + SiO_2.$$

In favor of some such reaction having taken place is the general absence of calcite veins from the rocks of the area, and especially the occurrence of veins of silicates high in lime such as vesuvianite, diopside and grossular garnet; and it is significant that veins of the latter kind are found most frequently, so far as present observations go, not in the vicinity of asbestos deposits, but adjacent to the chromite ore-bodies, which are associated with a rock containing considerable amounts of pyroxene. These occurrences are described in more detail below.

In any case, in so far as the Black Lake area is concerned, the further consideration of the monoclinic pyroxenes as an important source of the serpentine may be disregarded, and the same applies, in a lesser degree perhaps, to enstatite also. In the first place, the peridotite here contains in the neighborhood of 90 per cent. olivine, and microscopic examination of thin sections of the serpentine shows that the whole of this olivine has been completely altered; and secondly, of the relatively small amount of pyroxene present in the original rock, some at least has resisted the processes of metamorphism, and may still be seen as occasional crystals within the massive serpentine. The pyroxenes have evidently played a more important rôle in the genesis of the Broughton serpentine, and are doubtless also the source of the talc commonly associated with it.

NATURE OF REAGENTS PRODUCING THE METAMORPHISM.

The change which takes place in olivine is essentially one of hydration; but only in olivines of certain compositions, *i. e.*, those in which one fourth or more of the Mg is replaced by Fe, is hydration (plus oxidation) alone sufficient to bring about the change. The metamorphism of any olivine containing less iron than this requires the presence of some agent or agents in addition to water, and this additional material either enters into the molecule of the resulting serpentine, or is necessary in order to combine with those constituents of the original mineral which are not required for its formation.

In the present case, the evidence points to the olivine as being

of the latter type, with the ratio Mg : Fe = 5 : 1 or higher, and its conversion to serpentine must necessarily have been accompanied by (1) an enrichment in SiO_2 or (2) a loss of MgO. Reaction with siliceous waters would lead to the first result, while in the second case the excess of MgO is generally regarded as entering into combination as carbonate under the influence of waters charged with CO_2.

If all the iron present in the olivine does not remain combined in the serpentine, but separates partly or wholly as free oxide, it is necessary that the waters in each case contain also oxygen in some available form, in order that the ferrous oxide may be converted, entirely or in part, to the ferric state. In the present case it is probable that only a portion of the iron of the original olivine remains in combination in the resulting serpentine, the remainder separating as magnetite.

Assuming the formulæ $Mg_5FeSi_3O_{12}$ and $H_{88}Mg_{65}Fe_1Si_{44}O_{198}$ to represent the composition of the olivine and serpentine respectively, the metamorphism, if produced through the agency of siliceous waters, would proceed somewhat as follows:

$$(8) \qquad 3Mg_5FeSi_3O_{12} + SiO_2 + 10H_2O + O \rightarrow 5H_4Mg_3Si_2O_9 + Fe_3O_4.$$

The increase in volume is here 37 per cent., and the resulting mixture of serpentine and magnetite contains 7½ per cent. magnetite by volume.

To produce a serpentine of the calculated composition, the equation becomes

$$(8a) \qquad 13Mg_5FeSi_3O_{12} + 5SiO_2 + 44H_2O + 2O_2 \rightarrow H_{88}Mg_{65}Fe_1Si_{44}O_{198} + 4Fe_3O_4.$$

Increase in volume = 38 per cent.; magnetite = 7 per cent. of mixture.

Similarly, if the change be brought about by carbonated waters, the equations might be written

$$(9) \qquad 6Mg_5FeSi_3O_{12} + 3CO_2 + 18H_2O + O_2 \rightarrow 9H_4Mg_3Si_2O_9 + 3MgCO_3 + 2Fe_3O_4.$$

Total increase in volume = 34 per cent.; eliminating $MgCO_3$ = 25 per cent.; the serpentine-magnetite mixture contains 8½ per cent. magnetite by volume.

$$(9a) \quad 132Mg_5FeSi_3O_{12} + 75CO_2 + 396H_2O + 41O \rightarrow 9H_{88}Mg_{65}Fe_1Si_{44}O_{198} + 75MgCO_3 + 41Fe_3O_4.$$

Total increase in volume = 35 per cent.; eliminating $MgCO_3$ = 24 per cent.; the serpentine-magnetite mixture contains 8 per cent. magnetite by volume.

The volume relations are approximate, owing to the fact that the molecular volumes of olivine and serpentine of these compositions are not known; for the former, the value given by Van Hise for the compound with Mg : Fe = 3 : 1 is used, and for the latter the volume of the iron-free variety.

In each case the iron liberated is shown as separating in the form of Fe_3O_4; as is well known, magnetite is always present in the serpentine, and it is very possible that some at least of the magnetite which occurs disseminated through this rock, and also especially as a granular film along the centers of the asbestos veins, was derived from iron originally combined in the olivine of the peridotite; on the other hand, much of it may be magnetite which was present as such in the peridotite, and which remained unaffected by the metamorphic changes, except in so far that it may have been segregated and transported (possibly aided by its magnetic character) to the films just referred to, which marked in fact the positions of the fractures from which the alteration proceeded.

According to the above equations, the amount of magnetite produced is about the same in either type of reaction, and it is probably not in excess of that actually met with in the serpentine.

If siliceous waters are presumed to have been responsible for the alteration, magnetite is the only product, in addition to serpentine, which need necessarily be formed; by the action of carbonated waters, however, there must also result a considerable amount of $MgCO_3$, which, if formed, must have been completely removed as there is no evidence of it in the rocks.

From a quantitative standpoint, it will be found that the $MgCO_3$, if precipitated in the form of magnesite, would occupy approximately the following volumes, relatively to the serpentine:

Equation (2), serpentine : magnesite = 4 : 1 by volume.
Equation (9), serpentine : magnesite = 12 : 1 by volume.
Equation (9*a*), serpentine : magnesite = 10 : 1 by volume.

In other words, if the olivine and serpentine have the composition shown in equations (9) and (9*a*), and the magnesite was not removed, it would occupy a volume about half as great as that of the asbestos (on Dresser's estimate that entire serpentine band : asbestos vein = 6.6 : 1, or, massive serpentine : asbestos = 5.6 : 1); while if the olivine approaches more nearly to forsterite (as in equation (2)), there would be more magnesite than asbestos, by volume. Actually, the relative amount of magnesite would be considerably greater than is indicated by the above figures, as these are based on the amount of serpentine in the "bands," whereas the rock beyond these bands has also been serpentinized to a very appreciable degree.

While it may be readily admitted that $MgCO_3$ would be easily soluble under the conditions obtaining (hot solutions of CO_2 under high pressure), it hardly seems possible that, having once been produced in such comparatively large quantities, its removal could have been so complete as the field evidence would show to be necessary.

The difficulty which arises in accounting for the complete disappearance of the $MgCO_3$ is thus a strong argument against the hypothesis that carbonated waters were the agent of the metamorphism; and indirectly it favors siliceous waters as the active reagent, since the sole products in this case, serpentine and magnetite, are those which are actually met with. Moreover, as shown below, direct evidence indicating the presence of siliceous waters is not wanting, while there is nothing to show that waters charged with carbon dioxide were necessarily present at the time the alteration took place.

Summarizing, we find that siliceous waters, which were al-

most certainly available, are capable of reacting with olivine to give rise to serpentine (with magnetite also if the olivine is iron bearing) and no other product; this is in complete accord with the actual field occurrence.

The presence of carbonated waters, on the other hand, is entirely problematical, and even improbable; further, their reaction with olivine to give serpentine necessarily involves the simultaneous production of $MgCO_3$, and since the latter is not found accompanying the serpentine of this area, there arises the additional difficulty of accounting for its absence.

The conclusion is therefore drawn that the serpentine of the Black Lake-Thetford area has been derived from the alteration of the peridotite through the agency of siliceous waters.

THE EXPANSION ATTENDING THE ALTERATION.

The total expansion is about the same, whether the change is regarded as having been effected by siliceous or carbonated waters, although, obviously, if the carbonate formed in the latter case is removed, there must be a lesser increase in volume, since some magnesia is abstracted from the original olivine and carried away. At first it might seem that the amounts of expansion indicated are excessive, if not impossible, and that, if anything, they are an argument in favor of carbonated waters having produced the alteration; but they cease to be surprising when the volume of the peridotite affected is considered in relation to the whole mass of the rock. In the most extreme case, Dresser[6] refers to the asbestos veins as "occupying in places as much as 10 per cent. of the entire rock." Since he also estimates that the serpentine bands average 6.6 times the width of the asbestos, this would indicate that, in this favorable and exceptional case, the rock as a whole would be composed of 66 per cent. serpentine and 34 per cent. peridotite. In reality there would be considerably less serpentine, owing to the proximity of the asbestos veins to one another and to their many intersections, with consequent lowering of the ratio 6.6 : 1. However, taking the

[6] *Op. cit.*, p. 65.

percentage of serpentine as 66, and assuming the extreme case of equation (1) with an expansion of 40 per cent., this volume of serpentine would have been produced from 47 of peridotite, and thus the original rock had a relative volume of 34 + 47 or 81, which has been expanded to 100, an increase of about 23 per cent.

This case represents an extreme which is reached only seldom, and then on a relatively small scale. Althought the writer has made no actual estimate, his impression is that the amount of asbestos would not average one per cent. of the total rock if a reasonably large area were taken into account, in which case the total expansion through such a mass would be less than 2 per cent.

It is probable that the above calculation should be modified in that the amount of serpentine throughout the rocks, and the amount in the serpentine "bands," are not synonymous. That this is so is indicated by the presence of more than 9 per cent. of combined water in what are described as "typical specimens of the dunite" (see analyses above), which can only mean that even the apparently unaltered rock has been changed in a very considerable degree to serpentine; whereas Dresser's estimate of the relative volumes of massive serpentine and asbestos refers to the "bands" in which the metamorphism has been practically complete. Even with this correction, however, it is probable that the expansion throughout the whole mass of the peridotite, as a result of its partial alteration to serpentine, has not amounted to more than a few per cent.

SOURCE OF REAGENTS PRODUCING THE METAMORPHISM.

If, as supposed, siliceous waters have been responsible for the metamorphism of the peridotite, the question arises as to whether they were of meteoric or magmatic origin.

It is generally admitted that the serpentinization took place at a considerable depth below the earth's surface, though it might not be easy to submit direct evidence proving this to be the case. The region has been deeply truncated, and also there appears to be no diminution in the relative amount of serpentine (and asbestos)

with depth, although on the latter point little is definitely known, as our knowledge extends only for a few hundred feet below the present surface. The peridotite itself has all the characters of a deep-seated plutonic rock, and always lies below the other igneous rocks with which it is associated, *i. e.*, if the igneous complex takes the form of a batholith or stock, peridotite forms its central part, if a sill, the base. These features however provide no unanswerable argument in favor of the origin of the serpentine at depth, since the serpentinization might still be a comparatively recent phenomenon, which commenced after the erosion of the area, or progressed continuously with it.

If however it is admitted that the metamorphism is intimately connected with the intrusion of the granite dykes, then it follows that the conditions necessary for the alteration were brought about at a time long previous to the truncation of the overlying rocks, and at a depth far below the then existing surface. This would follow since the granite was intruded not much later, geologically, than the consolidation of the peridotite itself; and once the conditions favorable to the formation of serpentine arose, there is no reason to suppose its production was delayed. The field evidence undoubtedly points to the granite as having favorably influenced the formation of serpentine, since the number and width of the bands of this mineral may frequently be seen to increase in the vicinity of the dykes; and this circumstance affords the best confirmation of the hypothesis that the serpentine was formed at depth. It is of course evident that the rocks were not below the zone of fracture, for it is impossible to conceive of alterations of this type, accompanied by an expansion of the rock masses, as taking place within the zone of flowage.

Incidentally, the hypothesis that the serpentine has originated at such depths is distinctly unfavorable to the possibility of carbonated waters having played any part in its formation; not because such waters could not have descended to the scene, but owing to the improbability of the magnesium carbonate formed during the reaction being able to leave it.

The mere fact of depth does not preclude the possibility of the metamorphism having been brought about by descending (mete-

oric) siliceous waters. Since however the decision lies between a problematical supply of such waters, and an almost certainly established source of available magmatic waters which fully explain all the relations, both on theoretical grounds and as seen in the field, it seems more logical to regard the latter as the agent which has affected the alteration of the peridotite.

EVIDENCE THAT MAGMATIC SILICEOUS WATERS WERE AVAILABLE.

Direct evidence that the granitic injections were accompanied by hydrothermal waters, capable of producing somewhat intense pneumatolitic action, is supplied by certain dykes of vesuvianite, grossular garnet and diopside which are found cutting the serpentine in many of the asbestos and chromite pits, particularly the latter. These dykes are, as a rule, white or light colored (some of those composed of vesuvianite are deep lilac) and fine grained, although occasionally they are very coarsely crystallized, as is the case with some diopside dykes at the Montreal chrome pit. Except on close examination, therefore, they might easily be mistaken for ordinary aplite or pegmatite dykes, and it is no doubt largely owing to this that their true character has been generally overlooked in the past and that they have not been distinguished from the granitic dykes. So far as can be found, there has hitherto been no mention of the occurrence of such dykes in the published descriptions of the geology of the asbestos pits, while the lilac vesuvianite dykes at the Montreal chrome pit are specifically referred to by Cirkel[7] as "granite." The first record that the latter are not granite appears in Dresser's report, and the specimens which he collected proved, on examination by the writer, to be composed entirely of the mineral vesuvianite. Dresser[8] describes the mineral as occurring in "shoots, veins and irregular vugs" at several of the chromite pits, and he states that

"The occurrence of vesuvianite in two of the chromite deposits indicates that there has been pneumatolitic action. But granite intrusions

[7] Report on the Chrome Iron Ore Deposits in the Eastern Townships of the Province of Quebec, by Fritz Cirkel, Mines Branch, Dept. of Mines, Ottawa, Canada, 1909, page 27.

[8] *Op. cit.*, pp. 80 and 90.

which are found near each of these deposits were formed somewhat later than the rock which contains the chromite. It is, therefore, certainly possible, and seems more probable, that the vesuvianite was formed by pneumatolitic action due to the intrusion of the granite, rather than to the intrusion of the basic rocks."

Examination has shown that these lime-silicate dykes are by no means limited to the vicinity of the chromite deposits, but that they occur also, though perhaps not so commonly, cutting the chrysotile-rich serpentine. Further, there seems to be definite confirmation of Dresser's view that they are intimately related to the granite dykes, and that they have resulted from pneumatolitic action accompanying the injection of the latter.

The field evidence on this point is as follows: Aplitic dykes of normal character, containing little or no garnet are frequent, but occasionally they are found to be highly garnetiferous, while in other cases the aplite is traversed by narrow veinlets of fine granular garnet. It is difficult to avoid the impression that all gradations exist between the normal aplite and the dyke composed entirely of garnet, and that an aplite might be found to gradually change into a garnet (or vesuvianite or diopside) dyke in one and the same continuous fissure, although such an ideal case has hitherto not been observed.

The mode of origin of these dykes has been discussed by E. Poitevin and the writer in a monograph[9] dealing with the mineralogy of the Black Lake area, and may be briefly summarized as follows: In the first place it is very evident that these lime-alumina silicates have not been produced through the contact metamorphism of impure limestones, since the sedimentary series into which the peridotite and related rocks have intruded does not include any limestone beds, and further the occurrences have the attitude of ordinary dykes, enclosed on each side by serpentine. The only possible source of the lime, and also of the alumina, which these minerals contain, is apparently to be found in the pyroxene of the peridotite and pyroxenite bodies. It is believed, therefore, that the granitic magma, as it made its way along fissures in the peridotite and associated rocks, was able to exert a

[9] Museum Bulletin, Geol. Survey Branch, Dept. of Mines, Ottawa (in press).

powerful solvent action on the very basic minerals it encountered, owing mainly no doubt to its own extreme acid composition and to its content of aqueous and other volatile constituents; and as a result, the lime, alumina and some of the magnesia of these basic minerals have been removed in solution. The magma later assuming the solid form, gave rise, according to the conditions obtaining, to normal aplite, garnetiferous aplite or compact garnet dykes, while in other cases diopside or vesuvianite has been formed instead of garnet.

Whether the pneumatolitic action accompanying all the isolated injections of granite was equally intense cannot be determined, but it is possible that originally most or all of the granite dykes may have passed upward by gradual transition into dykes of lime-silicate minerals, and that the present comparative rarity of the latter is due to their having been removed by erosion, which in most cases has left only the normal granite roots of the dykes.

The composition of the invaded rocks would also be an important factor in determining their formation, and might explain the fact that such dykes seem to be relatively more abundant near the chromite deposits, than with the chrysotile; the former are all associated with a rock approaching a pyroxenite, while the chrysotile occurs in a rock which was originally a peridotite extremely poor in pyroxene.

If this hypothesis correctly explains the genesis of these lime-silicate dykes, it affords proof that the granitic magma, at least under certain suitable conditions, was capable of exerting a profound solvent action on the walls of the fissures it traversed. The material which has given rise to dykes of such acid composition as aplite is now generally regarded as having been, not so much in a molten state, as in the condition of a solution, or aqueo-igneous fusion. If it is admitted that such a solution was capable of dissolving and secreting material from the walls of the fissures it bathed, the writer would draw the conclusion that the residual aqueous and highly siliceous mother liquors not required for the formation of the granite and lime-silicate dykes were also capable of finding their way along many of the more or less closed joints and other cracks in the neighboring rock, insinuating them-

selves into the narrowest crevices and bringing about the alteration of the rock on either side to serpentine.

This hypothesis is quite irrespective of the actual age of the granite dykes, to which reference has already been made.

It may be objected that the number and size of the exposed granite dykes and masses are totally inadequate to have been responsible for serpentinization on the scale which has actually occurred, and that, even if the alteration has been effected by siliceous magmatic waters, these could not possibly have been derived entirely from the granitic magma. This question resolves itself largely into a matter of opinion as to the relative amount of such waters which might accompany a granitic magma, and that this amount has been variable at any given horizon in the Black Lake area is probable from the fact that the granite dykes do not always seem to have had an equal influence on the degree of serpentinization of the adjoining rock. There is also the possibility that the exposed dykes are merely the offshoots of larger bodies of granite which have not yet been uncovered; this might even be regarded as a probability should it ever be proved that the dykes belong to a later period of igneous activity than do the basic rocks of the serpentine belt, a view which is not held by those who have examined the area carefully. On the other hand, hydrothermal siliceous waters capable of producing serpentinization may have escaped from the peridotite magma as it crystallized, either before it had reached the extreme composition of a granite, or, in other cases, where the differentiation never proceeded so far. If such was the case, serpentinization would have commenced prior to the injection of the granite dykes; but the mode of occurrence of the serpentine in "bands" indicates that, at least in the main, the alteration of the rock originated along joint planes, and if, as believed by the writer, these were injected by the granite soon after their formation, the hypothesis here outlined for the origin of the serpentine is not materially affected.

The peridotite, then, within the zone of fracture, may be supposed to have been still at a fairly high temperature, but cooling. The stresses set up under these conditions within the contracting mass were relieved by a general shattering along well-defined

systems of joint planes, and also by subsidiary fractures. Any open fissures so produced, or rather, perhaps, the more pronounced and continuous fissures, were injected by granitic magma, which represented the last and most acid differentiate of the original magma from which the peridotite itself was the first portion to separate. In this way there originated the granite dykes which are so prevalent cutting the peridotite in the vicinity of the serpentine bands. The acidic, *i. e.*, highly siliceous, magmatic "extract" not required in the formation of the granite, and which contained all the water and other volatile constituents of the original magma, may well be supposed to have found its way along the joints and crevices in the surrounding peridotite, and to have exerted a very intense action on the rock, from which it differed so widely in chemical composition.

The writer would draw a strict analogy between these siliceous solutions and the quartz veins and stringers which are so commonly met with traversing bodies of granite, at least in so far as their source is concerned.

In the case of large granite masses, it is common to find that the last phases of intrusion have taken the form of aplitic or pegmatitic dykes, which are more acid in composition than the main body of granite; they are, in other words, acid differentiates of the same magma which supplied the granite, and consequently are quite comparable with the granite (and aplite) dykes cutting the peridotite in this area, except that the differentiation in the former case has not given rise to rocks of such extreme compositions as in the latter. The granite, further, is usually traversed by still more acid veinlets, which in many cases are pure quartz; these represent the last remaining fraction of the magma which has been left over after supplying the material of the dykes. Such highly siliceous magmatic solutions have traversed the fissures and cracks in the surrounding granite, but the latter rock being itself composed largely of quartz, with other fairly acid minerals, there was no tendency for any reaction to take place, and the solutions, depositing their silica, have given rise to stringers or irregular veinlets of quartz.

Many instances might also be cited of quartz veins, often of

considerable size, traversing granite, or even basic rocks, and which are clearly of pegmatitic character. Where such quartz veins traverse basic rocks and have not appreciably altered them, it is no doubt mainly because the rock and the quartz vein are not genetically related in any way, *i. e.*, the temperature of the siliceous solutions was low, and the invaded rocks had themselves long reached a temperature in equilibrium with their surroundings.

In the present case, however, the peridotite, granite and siliceous solutions were all originally present together in the same magma, and there was no great time interval between the consolidation of the first and the rendering available of the last. Such solutions, then, instead of meeting with acid minerals as they traversed the fractures in the surrounding rock (as in the case of the granite considered above), came in contact with olivine, the most basic of all the (igneous) rock-forming minerals, and also one of the most easily solube; and instead of merely depositing their silica along the fissures in the form of quartz veins, they reacted with the olivine to produce the less basic and more insoluble mineral, serpentine.

The alteration of the peridotite would thus go on progressively outward in both directions from the joints or crevices which served as channels for the supply of the necessary reagent. The width of the resulting band of serpentine would depend on several conditions, but mainly no doubt on the composition and texture of the original rock, the prominence of the fissure, its proximity to the main sources of supply of reagent, and on the continuance of the latter. This would explain why the widest and most persistent bands follow the rectilinear major joint system of the peridotite, those having other directions or more irregular courses being in general narrow. Further, given a fairly constant composition and texture for the peridotite, the rate of reaction should be approximately the same on each side of the fissure throughout its course, yielding bands with roughly parallel boundaries about equi-distant from the central crevice. It would be expected that these boundaries against the unaltered peridotite would be somewhat transitionary, and not sharply defined like the walls of a dyke, and such is borne out by the field evidence.

It is true Dresser[10] states that the boundaries are "nearly if not quite as sharply defined as that between the asbestos and serpentine," but the analyses, reproduced above, of specimens of peridotite taken from near an asbestos vein, indicate that beyond the serpentine band proper there is a zone of rock which has been serpentinized to a very considerable degree.

As a result of his observations in the field, Dresser has concluded that the serpentine, in addition to occurring along planes of jointing and strain fractures, is also found following fractures caused by exfoliation of the peridotite, and while he assigns to magmatic waters the rôle of having brought about the formation of the serpentine bordering the joints and strain fractures, he is of opinion that such waters would not have had access to the last type of openings, and that the serpentine now found along them owes its origin to meteoric waters.

These "exfoliation" fractures are in general smaller than those of the other two classes, and are of minor importance. Dresser[11] defines them as "fractures caused by exfoliation, or the casting off of concentric shells from angular blocks which have been previously separated from one another by fractures of the preceding classes (*i. e.*, joints and strain fractures). The increase in the volume of the rock when it is altered from peridotite to serpentine probably aids in forming fractures of this class."

The writer's view is that while the main bands of serpentine do undoubtedly appear to lie along the master joints due to shrinkage of the peridotite while cooling, and others may follow strain fractures caused by regional compression, the minor bands are so irregularly situated that it is impossible, with any degree of certainty, to assign any particular origin to the cracks they border. Many exposures may be seen, especially on the vertical walls in the asbestos quarries, where the rock is intersected in a truly amazing manner by asbestos veins (enclosed within serpentine bands) inclined to, and cutting, one another at every angle, some fairly straight and others curved or quite irregular in their course; though even these are dominated as a rule by the bands

[10] *Op. cit.*, p. 61.
[11] *Op. cit.*, p. 66.

following the rectilinear joints. Even if it could be demonstrated that some of these fractures are the result of exfoliation, the writer agrees with Dresser that their formation would have been aided by the expansion of the rock during its conversion to serpentine. While this would presuppose that some serpentinization had already taken place before the cracks of this type came into being, it does not thereby follow that the alteration of the rock bordering them began at a much later period than that along the main fractures. Expansion must have started and continued *pari passu* with serpentinization; and there seems no valid reason for supposing that the same siliceous waters which affected the one set of fissures did not also have access to the other. The fact that these "exfoliation" bands are in general narrow would indeed lend support to the view that serpentinization along the cracks they follow commenced somewhat later than in the wider ones.

Finally, the serpentine bordering such minor cracks is quite indistinguishable from that in the main bands, and where the two sets meet or intersect there is a continuity of the massive serpentine, and no break or other irregularity which might indicate that the mineral was formed, in the two cases, at widely different times or by different processes.

Since the evidence lends a fair degree of probability to the hypothesis that the whole of the serpentine was formed essentially at one time, or at least that its production, once begun, was continuous, and in the absence of any facts proving the contrary, it is here concluded that all the serpentine in the area has originated in one and the same way, through the agency of siliceous waters of magmatic origin.

An additional point which should be considered is that the serpentine is cut by granite dykes. In this connection Cirkel says:[12]

> "The serpentine is often cut by intrusive dykes of granite, which, as they fill fissures in the formation, appear to be of younger origin than the surrounding rock. . . . Sometimes these dykes cut off good asbestos chutes entirely; but, as a general rule, good ground is found on the other side of the dyke mass."

[12] "Chrysotile-Asbestos," *op. cit.*, p. 75.

At first sight such a feature appears to completely invalidate the whole hypothesis of the origin of the serpentine as outlined above, since, if the granite dykes are really later than the serpentine, it is obviously impossible that the siliceous waters associated with their injection could have had any bearing on the production of the mineral. It is probable, however, that the conclusion drawn by Cirkel as to their relative ages is erroneous, and the phenomenon certainly admits of a simple explanation which brings it in complete accord with the theory that the dykes were injected prior to the formation of serpentine.

This hypothesis practically demands a shattering of the peridotite, probably due to contraction of the cooling mass, before the intrusion of the dykes; in fact, without fracturing there could be no dykes. But it is not supposed that the intrusive magma welled up through all the fissures of the joint system, or even through an appreciable percentage of them; it made its way along the paths of least resistance, wherever it could force apart the walls of the fissures. The large majority of the joints doubtless remained closed, and so it is not surprising to find instances in the field where dykes cut across such fractures. At the time the dykes were intruded, however, the rock was peridotite, and it was only subsequently that serpentine began to be formed through the agency of the siliceous solutions expelled from the granite magma, and containing all the water and other volatile constituents of the parent magma. These solutions, aided no doubt by the low viscosity they possessed in virtue of their composition, may be imagined as percolating through all the more or less closed joints and other fissures in the vicinity of the dykes, and by a process of soaking into the peridotite to have brought about the gradual replacement of its olivine (and pyroxene) by serpentine.

Where a dyke intersected one of these joints, serpentinization may have proceeded along the latter on each side of the dyke, and it would even be remarkable if such did not happen, under the favorable circumstance of close proximity to the dyke. The result would be that, when laid bare by erosion, such an occurrence would present the apparent paradox of a dyke cutting the serpentine band.

THE ORIGIN OF CHRYSOTILE-ASBESTOS.

Views as to the manner in which the chrysotile has originated are somewhat at variance, but it is probably safe to say that the weight of modern opinion is in favor of the hypothesis that it has been formed *in situ* by direct replacement of the massive serpentine.

References to the literature dealing with this subject will be found in the reports of Cirkel and Dresser, and it is not necessary here to refer further to the different theories which have been advanced from time to time. Dresser summarizes the evidence, and his own conclusions, relating to the origin of the chrysotile, as follows:[13]

> "The position, size and number of asbestos veins in rich ground make it inconceivable that the spaces they now occupy were once open fissures, and especially that many of them were open at the same time. Open fissures up to 2 inches in width, running in all directions from vertical to horizontal, extending 100 feet or more in length, and occupying in places as much as 10 per cent. of the entire rock, would be a mechanical impossibility. The possibility remains of crevices having been enlarged and filled by replacement.
>
> "But the asbestos of the veins is practically identical in chemical composition with the serpentine of the walls, which is strong evidence against the material composing the veins having been brought in either from above or below. Segregation from the walls also would imply a difference in chemical composition, which does not exist. In other words, the material removed would have been replaced by material of exactly the same chemical composition, which is altogether improbable if not impossible.
>
> "It is therefore concluded that the veins are crystallized portions of the serpentine walls, and that the crystals (fibers) have grown outwards from the original crevices which are now represented by partings of iron ore found near the center of the veins. In cases where there is no such parting the growth of the crystals has taken place on one side of the fracture only. In most cases, however, there has been crystallization on both sides of the fracture, thus leaving a parting in the vein."

The writer's views coincide with the above. In addition, as first pointed out by Dresser, there appears to be a constant ratio between the width of any asbestos vein and that of the serpentine

[13] *Op. cit.*, pp. 65–66.

band which encloses it. If the chrysotile was deposited in open fissures, as has been held by some, it would be a remarkable circumstance that the openings should have been everywhere strictly proportionate to the thickness of the already formed massive serpentine on their walls. The close interdependence in the volumes of the two varieties affords the most significant evidence yet offered that the one is a direct replacement of the other.

Probably the main reason which has led some investigators to believe that the asbestos was deposited in open fissures, is its dyke-like character, enclosed by "walls" of massive serpentine, from which it separates fairly easily and cleanly. However, the definite character of the bounding "walls" is not nearly so real as it seems; microscopic examination of the junction shows it to be quite irregular, fibers of asbestos penetrating to various distances into the massive serpentine beyond, and the same feature is indeed apparent on mere inspection of most hand specimens. The plane in which the majority of the fibers terminate is necessarily a plane of weakness, and forms a zone along which the chrysotile can usually be broken away from the massive serpentine; but even at the best, the break is not clean, and, in mining parlance, deed apparent on mere inspection of most hand specimens. The dyke-like appearance, then, is due, in a large measure, to the two materials possessing such totally different structures, and also to their wide difference in color and luster. In the case of the junction between the peridotite and massive serpentine, which is nearly as sharply defined as that between the latter and the chrysotile, the dyke-like aspect is not so pronounced, because both materials are massive, and are so similar in color that on freshly broken surfaces it is often a matter of difficulty to distinguish the one from the other.

The field evidence thus lends a high degree of probability to the hypothesis that the chrysotile has directly replaced massive serpentine; but this theory gives no indication of the causes which have been responsible for the change, nor offers any suggestion as to the factors which may have favored it. In order to obtain possible evidence on this point, the relation between massive serpentine and chrysotile may first be considered.

THE RELATION BETWEEN MASSIVE SERPENTINE AND CHRYSOTILE.

Chemical Composition.

Comparatively few complete analyses of the serpentines from this area have been published. One of each variety, made by M. F. Connor, is reproduced above from Dresser's report; others will be found in Cirkel's monograph, but since analytical firms only are given as the authorities for these, it is doubtful how much weight should be attached to them, or whether they are to be considered as exact analyses. However, a review of all the analyses indicates that there is little or no essential difference in the chemical composition of the massive and fibrous material.

Taking the average, the analyses show less iron in the chrysotile, but this may no doubt be largely ascribed to the fact that the iron ore, which is always present, is for the most part segrégated along the central parting plane in the asbestos veins, whereas in the massive serpentine it is irregularly disseminated, so that unless very special precautions are taken in selecting the sample for analysis, there is much greater danger of an admixture of magnetite in the latter case than in the former. Practically all the analyses show some Al_2O_3 in both varieties, and Connor's results suggest that this constituent is present in greater amount in the massive serpentine. The figures given by Cirkel are not so conclusive, and, especially in the chrysotile analyses, they are rather widely divergent, ranging from *nil* to 3.67 per cent.; it is significant, however, that in each of the four analyses given, there is a corresponding fluctuation in the MgO content, and further that a high percentage of Al_2O_3 is accompanied by a low percentage of MgO, and vice versa, which might possibly mean that some MgO was precipitated along with the Al_2O_3, as commonly happens in the analysis of substances containing large amounts of magnesia unless the precipitate with ammonium hydrate is dissolved and re-precipitated several times. Also owing to the fact that the Al_2O_3 is precipitated, in the course of the analysis, together with the iron, and estimated by difference after the reduction of the latter, any incompleteness in the reduction process throws an

additional positive error on the Al_2O_3 which, in those cases where only a fraction of one per cent. of Al_2O_3 is shown in the analyses, might even be responsible for the whole of it. Lastly, the small amount of CaO which is usually found in the massive serpentine appears to be absent from chrysotile.

On the whole, then, the analyses are rather surprisingly similar, and the small differences which are observed are of the kind that might be expected because it is difficult to obtain the massive serpentine free from admixtures, such as magnetite and unaltered pyroxene. The conclusion is therefore drawn that the massive serpentine and chrysotile in the Black Lake area have identically the same composition. Recorded analyses of material from other localities, at which chrysotile is found associated with massive serpentine, reveal the same close correspondence in composition between the two varieties, and lend support to this conclusion.

Physical Characters.

Although massive serpentine is commonly regarded as being, to all intents and purposes, an amorphous substance, its specific gravity wherever found and however formed, falls within fairly narrow limits, usually between 2.50 and 2.65; these extremes are not wider apart than is common in the case of well-crystallized minerals of definite chemical composition, in which varying amounts of isomorphous replacement may take place.

In chrysotile, however, it might seem that there is a very wide range in the specific gravity, judging from determinations which have been published. Dana,[14] for instance, reproduces some analyses of chrysotile from various localities, and the specific gravity given for these ranges from 2.14 to 2.604. The same author, in describing chrysotile, gives the specific gravity as 2.219, and this value, or the range 2.2–2.3, has been reproduced in descriptions of the chrysotile from the Eastern Townships. In this way the impression has gained ground that the chrysotile at the latter locality is less dense than the massive serpentine with which it is associated, although apparently the statement has in no case been based on an actual determination of the specific gravity.

[14] "System of Mineralogy," 6th edition, p. 670 and p. 673.

Relying on this as the correct value, the writer was at first inclined to believe that the lower specific gravity of the chrysotile, as compared with massive serpentine, had been the determining factor, or at least a very important one, favoring the replacement of the latter by the former. Such a replacement would have involved an expansion in volume of more than 12 per cent., or, in other words, an asbestos vein 4½ inches wide would represent what had once been a 4-inch band of massive serpentine. Since the alteration of peridotite to serpentine is itself attended by an increase in volume, it was reasoned that there would be every tendency for any further change, involving an additional expansion, to take place.

A little consideration showed the improbability of there being such a wide difference in the specific gravity of massive serpentine and chrysotile. In the first place, a fibrous structure is not accompanied by a change in density in other substances or minerals (as hornblende, gypsum, etc.), and secondly, if chrysotile represents serpentine in the crystalline condition, as is sometimes thought, it would rather be expected to have a higher density, if anything, than the massive and practically amorphous substance. In order to clear up this point, several determinations of the specific gravity of each variety have been made. In the case of chrysotile, accurate determinations were made on fine threads, freed from all visible magnetite, using the pycnometer, while in other cases whole veins were taken, with as little of the massive serpentine attached as possible, and their specific gravity found by the hydrostatic weighing method; for the massive serpentine, the latter method was used throughout. The values found are given on the following page.

Except in the case of the larger specimens, the specific gravity was taken after boiling as well as in the ordinary way, and in every such case an appreciably higher value was obtained; in fact, it was found impossible to weigh accurately a piece of massive serpentine immersed in water unless it had been previously boiled, since its apparent weight continually and rather rapidly increases as the water soaks through its pores. The boiling was continued for not less than 2 hours, and the specimen then allowed

SPECIFIC GRAVITY OF CHRYSOTILE.

No.	Sp. G.	Weight of Specimen in Gms.	Nature of Material.	Remarks.
1...	2.58	0.8074	Picked threads. No visible magnetite.	Boiled 2 hours.
2...	2.56	0.6656	Picked threads. No visible magnetite.	Boiled 2 hours.
3...	2.50	1.2815	Columnar bundles of fibers. No visible magnetite.	Not boiled.
4*a*..	2.51	26.9138	One inch vein complete.	Before boiling.
4*b*..	2.53	26.9138	No visible magnetite.	After boiling
5...	2.62	2,163.71	Large vein complete.	Not boiled.
6...	2.68	312.93	Large vein complete.	Not boiled.
7...	2.34	244.27	Large vein (cracked specimen).	Not boiled.

SPECIFIC GRAVITY OF MASSIVE SERPENTINE.

No.	Sp. G.	Weight of Specimen in Gms.	Nature of Material.	Remarks.
8..	2.56	6.8217	Typical. Traversed by few very minute asbestos veins. Only very little visible magnetite.	Boiled 2 hours.
9..	2.57	776.95	Adjacent to 1½" vein.	Not boiled.
10*a*.	2.52	10.0147	Adjacent to 2" vein.	Before boiling.
10*b*.	2.55	10.0147	Very little visible magnetite.	After boiling.
11*a*.	2.49	9.1220	Olive green, very compact, with slickensided faces.	Before boiling.
11*b*.	2.58	9.1220	No visible magnetite.	After boiling.
12*a*.	2.63	12.5090	Similar to No. 11, but dark green in color.	Before boiling.
12*b*.	2.64	12.5090		After boiling.
13..	2.72	30.5812	Abt. 4" distant from 1" vein.	Not boiled.
14..	2.88	10.2295	Average magnetite content.	Not boiled.

to cool over night while still immersed, after which its weight was found to be constant. The results indicate that the porosity is of the same order in both massive serpentine and chrysotile.

In determinations (1) and (2) loose frayed threads of fiber, carefully freed from all visible magnetite, were used, and their mean, 2.57, may be taken as the specific gravity of the chrysotile. The higher values in (5) and (6), in each of which the whole vein was used, are due to the admixed magnetite. The presence of one per cent. of magnetite would raise the apparent specific gravity of chrysotile by about 0.025, indicating a content in these cases of three or four per cent. magnetite. Determination (7) is added as offering a possible explanation of the low values which have sometimes been reported; in the present case the low result is certainly due to the fact that the specimen was cracked, and being thus made up of a number of loosely bound

bundles of fibers separated by air films, it displaced more water than it would have done had it been in an undamaged and compact condition.

That the massive serpentine is certainly not denser than the chrysotile is shown by determinations (8) to (11), which range from 2.55 to 2.58. The fact that in these experiments comparatively large pieces were used, and that the foreign substances likely to be present (magnetite and pyroxene) are heavier than the serpentine itself, might even be taken as indicating that, if anything, chrysotile is the denser of the two. The higher value in (12) was obtained on a very dark green specimen and is no doubt to be referred to a greater replacement of Mg by Fe here than in the average serpentine. Numbers (13) and (14) are of interest as showing the effect of distance from the chrysotile vein, the high values being due to the fact that the serpentine contains a considerable amount of incompletely altered pyroxene.

It would appear, then, that massive serpentine and chrysotile not only have the same composition, but also the same density, and that we are not dealing here with a case of dimorphism.

No appreciable difference in the hardness of the two varieties is observable.

Optical and Microscopic Characters.

In none of its varieties does serpentine exhibit well-defined optical characters when examined in thin section under the microscope, owing mainly to its imperfect crystalline character. It is always biaxial, with refractive indices and birefringence rather higher than for quartz; the fibers are optically positive, but certain platy varieties appear to be negative.

In the area under discussion, almost the whole of the serpentine has been derived from the alteration of olivine, and sections may be obtained showing all stages of this alteration, from the fresh peridotite to the massive serpentine rock. The serpentinization follows the course which is usual under these conditions, commencing around the margins of, and along cracks in, the olivine crystals, and proceeding inwards toward the center of the

crystal, until finally the latter has been completely altered to serpentine, although even then the outline of the original crystal may still sometimes be discerned. Most frequently the serpentine which forms along the cracks is in the form of parallel fibers, lying transverse to the crack, while that around the margins also appears as fibers, more or less parallel, or rather radially arranged. Where the alteration has proceeded further, the interior of the olivine crystal is replaced, still by fibers, but these most usually have no particular orientation and appear rather as an irregular network.

There is nothing unusual in this mode of alteration of olivine to serpentine, but the feature it is desired to emphasize is that the serpentine so produced is generally *fibrous,* in very large measure if not entirely. The fibers, however, are quite microscopic in length, and for the most part do not lie parallel to one another, but are interwoven or felted, as a result of which specimens of the serpentine appear to the unaided eye, to have a thoroughly compact, massive texture.

Structurally, then, the difference between chrysotile and massive serpentine is one of degree and not of kind. The former name is used to denote those occurrences in which the fibers are so long as to be visible to the eye: they may lie parallel to one another (cross fiber), but not necessarily so (slip fiber). Where on the other hand the fibers are microscopic, with no regular orientation, their aggregation has built up the substance "massive" serpentine.

The above comparison of the main properties of massive serpentine and chrysotile has been presented rather fully with the view of showing their complete identity, although the fact that there is no essential difference between them is no doubt realized by most mineralogists. If due allowance be made for the difference in their crystalline perfection, it is probably safe to say that the three substances picrolite, chrysotile-asbestos and massive serpentine are related to one another in exactly the same way as are tremolite, hornblende-asbestos and nephrite.

THE CHANGE FROM MASSIVE SERPENTINE TO CHRYSOTILE.

Granting, then, that massive serpentine and chrysotile are in every way one and the same substance, the question as to the reason for the occurrence of veins of the latter resolves itself entirely into one concerning the conditions favorable to the formation of this more perfectly crystalline form of the mineral.

Although the serpentine they contain is identical in every way, there yet remains a great difference between the constitution of the chrysotile veins and the massive serpentine bands; this difference consists wholly in the absence or presence of admixed material, and depends also on the nature of the latter. In the veins, the serpentine is absolutely free from any foreign substance other than iron ore, and even this is for the most part segregated along a single plane near the center of the vein. The massive serpentine of the bands, on the other hand, always has associated with it, in addition to magnetite, a certain amount of unaltered, or incompletely altered, pyroxene, and this is true even in the zone immediately adjacent to the chrysotile; the magnetite, moreover, is here widely scattered in grains throughout the bands. It is reasonable to conclude, therefore, that the first condition necessary in order that veins of chrysotile may form is the complete serpentinization of all the ferro-magnesian minerals of the original rock, together with the complete removal of all other constituents, such as lime and alumina, which may be present, with the exception perhaps of iron ore.

The factors favoring such a complete alteration might not everywhere be the same; but it should be possible, in any particular case, to obtain some indication of their nature from a consideration of the course which the metamorphism has taken.

In the present area, a cross-section from the peridotite to the chrysotile may be divided roughly into four zones, as follows: (1) unaltered peridotite; (2) partial serpentinization of the olivine, with pyroxene more or less unaffected; (3) olivine completely, and pyroxene partially, serpentinized—this zone constitutes the massive serpentine "bands"; (4) complete serpentinization of both olivine and pyroxene—this zone forms the chrysotile "veins."

Taken in this order, from (1) to (4), these four zones afford a picture of the manner in which the serpentinization of the peridotite has proceeded outward from the joint planes and other fissures, and they indicate that the process was of a gradual and selective nature. The siliceous solutions flowing along the joints and other crevices, and permeating the walls on either side, have first acted on the olivine content of the rock, attacking this mineral around the margins of the crystals and along the cracks traversing them, and from the resulting concentrated aqueous solutions of olivine, serpentine has been deposited in the form of microscopic fibers. The expansion attending this reaction doubtless tended to "loosen up" the peridotite affected, rendering it more porous, so that the solutions were able to reach fresh zones of the rock, further and further removed from the original fissures. Fresh supplies of reagent, in the course of their passage outward, were thus continually bathing the rock already partially altered, with the result that in the zone immediately bordering the fissures, the serpentinization of the rock has been complete, while beyond this there is a more or less gradual transition until the unaffected peridotite is reached.

The change in the structure of the rock follows a similar course, increasing with the degree of serpentinization. Thus, the massive granitic structure of the original peridotite has not entirely disappeared even in the serpentine "band," where the outlines of what were olivine crystals may still be sometimes traced, and where, further, more or less unaltered pyroxene crystals yet remain and the magnetite is disseminated much as it occurs in the peridotite. It is only in the chrysotile vein proper that the original structure is entirely lost, even to the extent that most of the iron ore has here collected along certain definite zones.

From this it would seem to follow that in the early stages of the process, the structure of the peridotite was hardly at all affected, and that until its serpentinization was fairly complete, the rock remained essentially a solid mass, although sufficiently porous, partly as a result of its expansion, to admit of the free passage of the solutions. But the serpentinization involves expansion, and therefore also a loosening up of the rock and an

increase in its porosity, and these latter features in turn promote the serpentinization. Thus, in the final stages, where the rock has been completely serpentinized, its porosity must be at a maximum, or, in other words, it must be completely saturated with the solutions which effect the serpentinization, and its original structure is lost.

This result is naturally first attained in the zone or film bordering the fissure, which is then composed entirely of fibers, possibly still microscopic in length, of serpentine. The chrysotile of the veins is believed to be the result of the parallel position and transverse attitude assumed, at the very outset, by these very minute fibers, and of their subsequent growth in one direction only, *i. e.*, outward from the fissure, as successive new zones of rock became completely serpentinized; and the ultimate length of the fibers was limited only by the width attained by this completely serpentinized zone.

In the present state of our knowledge concerning the causes which determine or influence the habit of crystals, it may, perhaps, seem idle to discuss possible reasons for the extremely acicular character of the crystals or fibers. It might be said that this is the common habit of "crystals" of serpentine, just as, for instance, it is the common habit of crystals of mesolite; and it is certain that such a habit may be determined by one or more of several factors, such as the temperature and concentration of the crystallizing liquid or solution, and also by pressure. A crystal growing under ideal conditions, *i. e.*, surrounded on all sides by solution of equal concentration and under the same pressure from all directions, may (except in the case of cubic substances) develop a prismatic habit, more or less pronounced, which is entirely the result of the intermolecular forces set up during crystallization; on the other hand, a growing crystal which is not so surrounded, will have its habit controlled in very large measure by external causes. Generally speaking, it may be said that the crystal will grow only in those directions in which it is in contact with a supply of supersaturated solution, and if only the extremity, or both extremities, of the crystal, are so supplied, there will result an acicular or asbestiform habit.

Among possible ways in which this last condition would be realized, the three following may be referred to:

1. The crystal, with the exception of its extreme tip, might be entirely removed from the influence of the solution as fast as it grew, either through being pulled or pushed out from the solution, or by the continual relative withdrawal of the latter from the growing crystal; as an example among minerals might be cited the fibrous structure of many stalactites, in which the fibers continue to increase in length through contact at their outer ends with evaporating solutions of carbonate of lime.

2. When crystallization commences at any point in a supersaturated solution, it frequently happens that the crystals at first grow extremely rapidly, and in one direction only, giving rise to acicular or hair-like individuals, no matter what the normal habit of the substance may be, the reason for this being that the tip of each crystal is continuously jutting into fresh supplies of supersaturated solution, while the liquid bordering its sides is correspondingly impoverished by reason of the material abstracted by the growing crystal. When a drop of such a solution is observed under the microscope it is usually seen that the needles radiate in all directions from each center or point of crystallization, and it is possible that the radiated fibrous habit met with in some minerals has, in many cases, originated in this way.

3. The solubility of crystals is affected by pressure. If a substance crystallizes with increase in volume, any increase in the pressure may prevent its further growth or cause it to re-dissolve, whereas a relief in the pressure will hasten its growth. Assuming such a substance to be in the liquid state or in concentrated solution, and under such a uniform pressure that it is just prevented from crystallizing; then, if the pressure in one direction is reduced, crystallization will immediately commence. The crystals, however, can only grow where they are in equilibrium with the liquid or solution, that is, in the direction of least pressure, and so they assume an acicular or asbestiform habit; moreover in this case the fibers will be all arranged parallel to one another.

While, then, there may be many alternative ways in which a fibrous habit might originate, the possibilities should be some-

what limited when this character is combined, as it is in the case of chrysotile veins, with a strict parallelism of the fibers; and they should be still more limited when it is found that the attitude of these fibers is always transverse to their bounding walls.

Both the parallelism of the fibers and their transverse attitude are structural features which are indicative of an expansive, rather than a compressive, strain. At first sight it might seem that the existence of such a strain would be impossible or unlikely, in view of the fact that serpentinization is attended by an increase in the volume of the rock affected, which might be expected to result in compression. According to the views advanced here, however, the peridotite batholith was a cooling mass at the time it was undergoing alteration to serpentine, and it seems not impossible that the total amount of contraction due to cooling may have been so great, or perhaps its rate may have been so rapid, that, in spite of the expansion involved in the local serpentinization, there was a tendency for the joint planes and other fissures to open, and as a consequence the material adjacent to them was subjected to an expansive strain, normal to the walls.

The full force of such a strain would necessarily be exerted at the fractures, because they were planes of weakness; and it would affect only the completely serpentinized film, or layer, of rock parallel to these fractures, since, as indicated by its structure, the rock beyond remained essentially a solid mass until its complete metamorphism was effected.

Stated briefly, the writer's conclusions regarding the mode of origin of the chrysotile veins are as follows:

Siliceous magmatic waters, rising along fissures in the cooling and contracting peridotite, have soaked into the rock on either side and brought about its serpentinization. Complete alteration under these conditions was first reached in the layer of rock immediately bordering the fissure, while beyond this the degree of serpentinization decreased more or less gradually outward to the unaffected peridotite. Owing to the tendency for the fissures to open, this bordering layer of serpentine was not subjected to a uniform pressure from all directions, and the growing crystals were able to develop only in the direction of least pressure, nor-

mal to the fissure. The rock beyond, remaining essentially a solid mass until its serpentinization became complete, was not materially affected by this circumstance; but as succeeding layers or films, further and further removed from the original fissure, became completely serpentinized, the crystals continued to grow outward, because it was only at their extremities that they were in contact with fresh supplies of material, and also because the lesser pressure normal to the walls aided their growth in this direction. The original walls of the fissures, and also successive zones or layers of rock beyond, have in this way been continually eaten away and destroyed by the serpentinizing waters, and their solution has afforded the material from which the fibers of the chrysotile veins have crystallized; these fibers growing outward as the walls receded further and further through solution.

Ultimately, the formation of chrysotile ceased, either because the supply of serpentinizing waters was discontinued, or because there was no further tendency for the fissures to open; if the latter, this might have been due to the main body of peridotite having reached a temperature in equilibrium with its surroundings and ceased contracting, or to its rate of contraction having become insufficient to counterbalance the expansion attending further serpentinization. In this case the formation of serpentine would still proceed, but the rock affected, being now under a more or less symmetrical pressure, the fibers would not be forced to assume any particular orientation relative to one another, and "massive" material would result. The fact that Dresser found a fairly constant ratio between the width of the chrysotile veins and the serpentine "bands" which enclose them, suggests, however, that the formation of both proceeded side by side and ceased simultaneously, and consequently it may be concluded that it was lack of the necessary reagents which finally determined the width of any chrysotile vein.

The point might be raised that, since the serpentinizing waters, in the course of their passage from the fissure to the unaltered or incompletely altered rock beyond, must have been continually passing across the whole width of the chrysotile vein in process of formation, the delicate fibers would have been redissolved.

However, it does not necessarily follow that a reagent which was capable of dissolving olivine, and even pyroxene, was an equally powerful solvent for chrysotile, and in fact it may have had little or no action on the latter. The writer is inclined to the view that re-solution of the fibers did perhaps take place to some extent, especially at their extreme tips adjacent to the fissures (but without of course any actual opening of the latter), the material being redeposited further along in the vein. A repeated recrystallization such as this might go far to explain the extreme delicacy, purity and uniform character of the chrysotile fibers, and also the absence of admixed foreign material from the veins, since all the iron ore, being insoluble, would be left behind and accumulate at the fissure. It might also throw some light on the frequent wavy or uneven nature of this central parting of iron ore (generally regarded as marking the plane of the original fissure), which is somewhat difficult to account for, since, on the above view, a partial, but not uniform, solution of the fiber tips might lead to a shifting or wandering to one side or the other of the original plane of the fissure.

According to the above hypothesis, two conditions must be fulfilled before veins of chrysotile can form. These are:

1. The production of pure serpentine, *i. e.*, the complete serpentinization of all the silicate minerals of the peridotite, or other parent rock, together with the complete removal of all those constituents which are not required for the formation of the serpentine molecule (except perhaps iron ore).

2. The pure serpentine, as it crystallizes, must be under a differential pressure, *i. e.*, subjected to an expansive strain in one direction, which will determine the direction of elongation of the fibers.

The necessity for the first condition will be generally admitted; and yet there must be some other requisite, or chrysotile would be a very much more widespread and common substance than it actually is. The writer believes this is supplied by the second condition above. The expansive strain may perhaps not everywhere result from the same causes; in the present instance it is

suggested that the rock undergoing serpentinization was a cooling mass, whose rate of contraction was equal to, or slightly in excess of, the rate of expansion attending its local serpentinization, and that, as a consequence, there was a tendency for any cracks traversing the rock to open.

This view is bound up with the entire theory outlined above for the mode of origin of the serpentine in this area. It depends on the belief that serpentinization commenced moderately soon after the consolidation of the peridotite, and that it was brought about by waters which were present in the original magma from which this rock separated, and which were expelled, for the most part, at least, during the final stage of intrusion, that of the granitic dykes.

It would follow as a corollary to this hypothesis, that chrysotile veins would never be found in cases where there was no contraction of the rock masses to counteract the expansion incident to serpentinization, since in that event, even if pure serpentine was formed, the rock would be under essentially the same pressure from all directions; the microscopic fibers would not be constrained to assume any regular orientation, and would give rise to ordinary "massive" serpentine rock.

Thus, where the metamorphism has been brought about by meteoric waters, only massive, and usually impure, serpentine should result, and so far as the writer is aware, chrysotile veins of appreciable width or abundance have never been found associated with massive serpentine which can be shown to have originated in this way. On the other hand, where the serpentine is regarded as having been produced through the agency of magmatic waters, and has no associated chrysotile, it is possible that these waters were not genetically connected with the parent rock of the serpentine mass, and only reacted upon it long after it had reached the normal temperature and ceased contracting; and in many cases, also, it may be that the metamorphism did not progress so far as to realize the first condition of complete serpentinization.

CURVED OR BENT FIBER.

While the fibers in a chrysotile vein are usually quite straight and normal to the wall, it sometimes happens that they are bent, while still retaining their parallelism. Generally, in such cases, the fibers proceed normally from one wall, bend downward or upward, and later resume their original trend, with which they reach the other wall. The bending may persist through a considerable length of the vein, or possibly even throughout an entire vein, along a line (or rather a plane) about parallel to the wall; it may or may not follow the center of the vein, and there may even be more than one line of bending in a single vein. The writer unfortunately did not observe this feature sufficiently carefully when in the field to be able to state definitely whether or not bent fiber occurs only in the more or less vertical veins, but is under the impression that it is to be met with equally in all veins, quite irrespective of their attitude, but more commonly perhaps in the narrow ones than in those of greater width. It is certain that the bend is seldom if ever sharp and angular, but takes the form of a gentle curve.

Such occurrences as these have usually been attributed to movement of the walls (faulting) subsequent to the formation of the chrysotile veins. As opposed to this view, Mr. Dresser informs me that he has observed bent fiber in mere gash veins only a few feet in length, where lateral movement could not possibly have taken place.

The writer would suggest that the bending of the fiber is to be explained as a result of the influence which neighboring veins have had upon one another during their growth. If the rock undergoing serpentinization was traversed by a series of parallel fissures, then the expansive strain set up by reason of their tendency to open would be everywhere exerted in one and the same direction, and straight fibers, normal to the walls, should result; but where there are, in addition, intermediate fissures having various inclinations to these and to one another, the case is not so simple. Each fissure, while tending to open normally, will be influenced by every other fissure, to an extent depending upon its

prominence and nearness, and the direction of the expansive strain at any point will be the resultant of all these combined, and might vary from time to time. As a consequence, the fiber in any particular vein, instead of stretching across normally from one wall to the other, may be disturbed, curved or bent, although at the same time its general direction will be dominated by the attitude of the fissure it follows.

SLIP-FIBER.

This term is used to define those occurrences in which the chrysotile fibers, instead of lying transversely, have their length parallel to the fissure walls. Owing to the manner of occurrence, such fiber may appear to have a very considerable length, but this is due to the overlapping of short fibers which are all matted together in more or less parallel position, and examination shows that the slip-fiber is in reality usually shorter than the average transverse vein-fiber. As the name suggests, the field indications are that this variety of fiber always follows planes of slipping or shearing; there is apparently no evidence to show whether it was formed prior to the cross-fiber veins, or at some subsequent time. This type of occurrence is not at all common in the Black Lake-Thetford district.

THE JUNCTION AND INTERSECTION OF CHRYSOTILE VEINS.

Under favorable conditions, such as are to be found especially in the producing quarries, the massive rock is traversed by a very complex network of veins, which meet, and also intersect, one another at all angles. Where two veins, inclined at a small angle, meet, they may continue as a single vein. An occurrence of this kind apparently represents either a single fissure which branched at one or more points along its course, or two nearly adjacent but slightly diverging fissures, in which case one may have been formed subsequently to the other as the serpentinization progressed; and from the simple or compound character of the vein below (or above) the forking, it is often possible to

decide with some certainty which of these alternatives actually gave rise to any particular occurrence of this nature. Such branching veins may again meet and thus enclose blocks or fragments of massive serpentine. Owing to their nearly parallel courses, there is seldom any disturbance in the direction of the fiber at the point where veins of this type fork.

Where veins meet at wider angles, they usually intersect, each continuing on the other side of the junction with direction and position unchanged; a relatively narrow vein, however, may appear on one side only of such a junction, or it may pinch out after continuing for a short distance on the other side. If one of the veins is appreciably wider than the other, it is the general rule, and from the writer's observations the invariable rule, that the fiber in the wider one is continuous and not at all disturbed by the intersection with the other; it appears to cut across the smaller vein just as cleanly as a younger dyke might cut across an older. With the chrysotile veins, however, it can hardly be doubted that the relative ages of the two are just the reverse of this, and that it is the continuous vein which is the older. The wide veins, which are usually fairly straight and persistent, represent the most prominent fissures, and in many cases the major joint planes, of the peridotite, along which its serpentinization first commenced; many of the narrower ones, on the other hand, are believed to follow cracks which were developed from time to time as the alteration proceeded. That this view of their age relations is the correct one receives confirmation from a closer examination of many such intersections, in which the smaller vein may be seen to penetrate for a greater or lesser distance into the wider one, indicating that, after the main vein had attained a certain width, serpentinization commenced along a fissure intersecting it, and that thereafter the outward growth of the two veins proceeded simultaneously. For the same reason there is often a considerable amount of disturbance and confusion in the direction of the fiber where two veins of approximately the same width intersect.

INCLUSIONS OF MASSIVE SERPENTINE WITHIN THE VEINS.

Fragments of massive serpentine are occasionally seen enclosed entirely within veins of chrysotile, and situated, more often than not, near the central parting. In some cases the relations are such as to leave little doubt as to the correct explanation of the occurrence, since the massive material is clearly a fragment included between two or more branching veins of chrysotile. In other cases, however, the inclusions are more irregular or smaller, and the reason for their presence within the veins is not so self-evident. It seems probable that they are not always to be explained in the same way, and without attempting to exhaust the various possibilities, the two following may be suggested.

The inclusions may in some cases represent the last remains of what was originally a narrow zone of rock lying between two adjacent parallel fissures, where the process of serpentinization was arrested before the outward growth of the fibers from each of the fissures had proceeded sufficiently far to effect a complete coalescence of the two resulting veins, which consequently remain separated here and there by fragments of the still incompletely serpentinized massive rock.

Again, it is possible that the original walls of a fissure might have been intersected by subsidiary cracks to such an extent that the waters, passing along these, have reached the sounder rock beyond, completely surrounding fragments, which were left as islands of partially serpentinized massive rock within the growing vein of cross-fiber; and the same might happen at any similarly fractured zone beyond the original fissure, as the outward progression of complete serpentinization (the chrysotile vein) reached it.

REVIEW

Die Entstehung der unterelsaessischen Erdoellager erlaeutert on der Schichtenfolge im Oligocaen. By L. von Werveke. Mitt. 5, Philemathisch. Ges. in Elsass-Lothringen, Bd. 4, 1913, S. 697–721.

From a careful study of the cores from several deep bore-holes in the oil region of Lower Alsace the author determined the following section:

	Meters.
Gray marls	375
Alternating beds of variegated marls (with numerous sun-cracked layers)	475
Upper part: Variegated marine marls containing anhydrite alternating with gray, green, red and brown freshwater marls, containing sandstone layers with *Limnæus* and *Planorbis*.	
Lower part: Variegated highly fossiliferous marine marls (with *Mytilus, Pecten, Mactra, Thracia, Hydrobia, Euchilus,* etc.) alternating with colored freshwater marls (with *Limnæus*), containing sandstone layers, locally rich in bitumen.	
Red marls, locally green, and sandstone (with *Limnæus*), containing bitumen	100
Gray and green freshwater marls (red or brown in lower part), with numerous sandstone layers (with suncracks and *Limnæus*)	150
Gray and black marine marls with anhydrite (no sandstone)	80
Locally, where freshwater and marine strata alternate, bitumen in small amount.	

This section has brought out the following points which, in the view of the author, speak strongly in favor of an origin in situ of the oil, as a consequence of the repeated destruction of animal life along a constantly shifting strand line, where marine and freshwater conditions, as well as changes from land to water, in general alternate.

1. The oil is found only in the freshwater sandstones that alternate with marine strata.

2. Where the freshwater deposits alternate with highly fossiliferous marine strata, the yield is greatest.

3. The oil is absent from freshwater strata that alternate with marine strata bearing anhydrite, the presence of which precludes the occurrence of fossils.

4. The oil is absent from the 150 meters of exclusively freshwater strata in the lower part of the section, although these beds contain

numerous layers of porous standstone. But it reappears at their lower passage into marine strata, where marine and freshwater deposits alternate.

5. The oil is not uniformly distributed in the oil-bearing sandstones, but exists in isolated pools separated by barren sandstone, although the region is intensely faulted.

6. The oil pools show no connection with fault lines.

7. No oil is found in the sandstones of the underlying Mesozoic formations, some of which would make excellent reservoirs.

8. The black Posidonia shale of lower Jurassic age was found in several deep bores to be perfectly fresh and unaltered. This is strong evidence that distillation has not played any rôle in the formation of oil in this region.

9. The fact that the geothermal gradients are unusually steep in the oil region is interpreted as indicating that the slow process of polymerisation of the oil in situ, being an exothermic process, is still in operation.

W. H. BUCHER.

SCIENTIFIC NOTES AND NEWS[1]

HOWLAND BANCROFT has returned to Denver after an extended visit to South America.

PROFESSOR J. F. KEMP is back at his desk at Columbia University, much improved in health and attending to a little work.

J. E. SPURR is in Nicaragua attending to some work in connection with the starting of milling operations of the Eden Mining Co., a subsidiary of the Tonopah Mining Co.

L. D. RICKETTS had an attack of pleurisy during the February meeting of the A. I. M. E., and his projected trip to Chile will be somewhat delayed.

D. W. BRUNTON has gone to China on business.

ADOLPH KNOPF, of the United States Geological Survey, has gone to the Rochester district, Nevada, to make a detailed survey of the small area in which the main operations of that region are confined.

ANNOUNCEMENT is made that applications for the Emmons Memorial Fellowship in Economic Geology will be considered and an incumbent appointed prior to the first of June. Applications should be sent to Prof. J. F. Kemp, of Columbia University, not later than May 15. The holder of this fellowship receives an income of $1,000 and is expected to carry on an investigation in economic geology which will add a distinct contribution to the literature. The institution at which the study is pursued will be decided after conference with the members of the committee of awards. The character of the investigation will be decided after applications have been passed upon.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.